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MALI RANGE SURVEY

FINAL REPORT

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FEBRUARY 1977

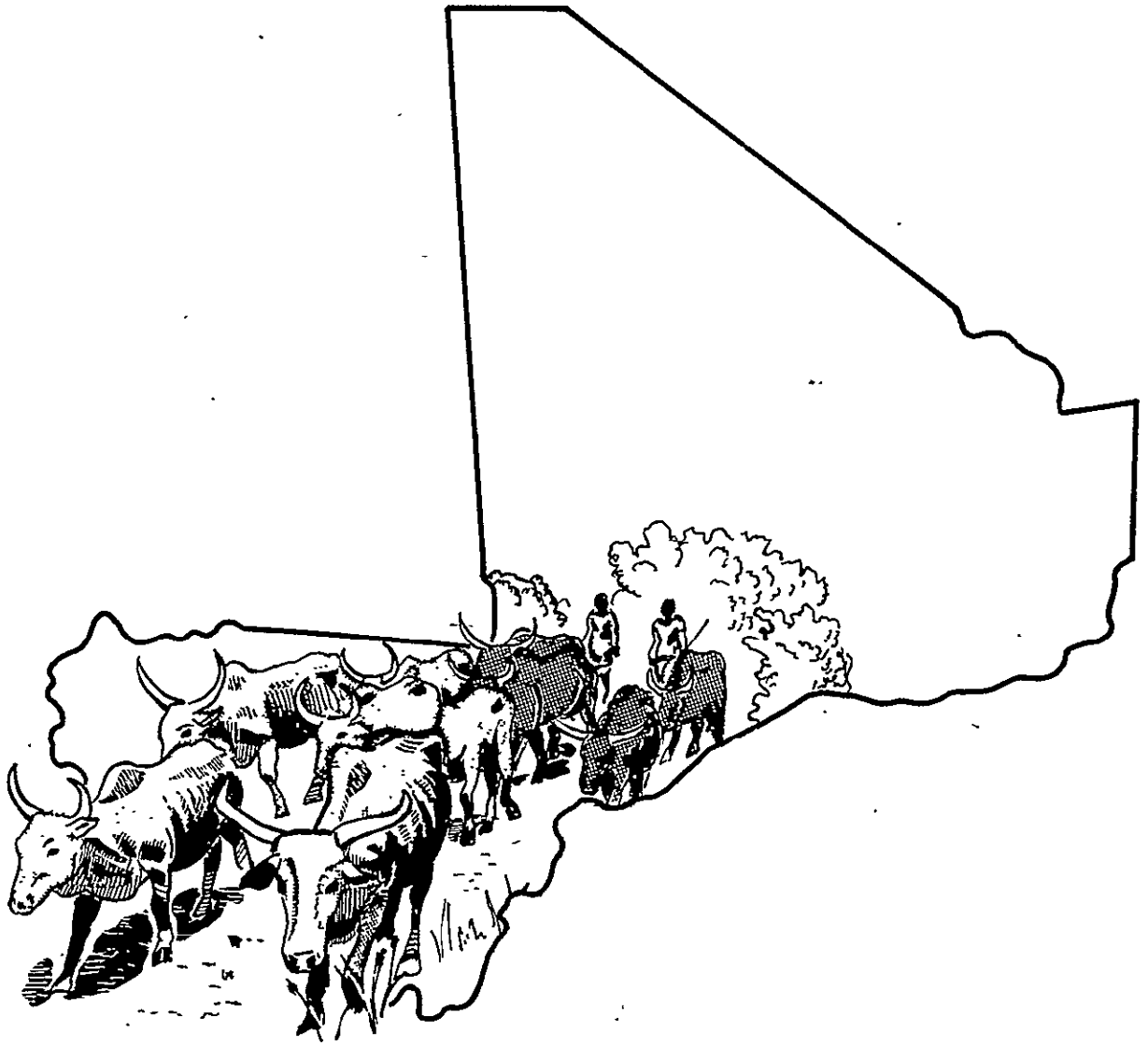
PREPARED FOR THE

GOVERNMENT OF THE REPUBLIC OF MALI

UNDER THE AUSPICES OF

THE UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT

MALI LIVESTOCK SECTOR STUDIES



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BY

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EXECUTIVE SUMMARY

Objectives

- The principal objectives of this contract were to: 1) provide the Government of the Republic of Mali (GRM) with basic information on the soils and vegetation resources of the Dilly area; 2) perform a reconnaissance level survey of the Newlands area which would provide information necessary to permit an informed choice as to which of three candidate areas is best suited for tsetse fly control; and 3) provide preliminary training and indoctrination in the principles, methods, techniques, and utilization of remote sensing in natural resource surveys.

- The contract was initiated in March, 1976, and all contract objectives were achieved by February, 1977.

Part I - Dilly Range Site Survey

- A semi-detailed study was made of range sites within the Dilly region using Skylab satellite imagery, 1:50,000, black-and-white and color infrared photography, and ground surveys. Graphic products (photographs and overlays) were produced which portray the following subjects:

    1. Burns
    2. Villages, roads, and trails
    3. Drainage and candidate areas for surface water development
    4. Ecological units
    5. Range utilization
    6. Base photomaps

- The information contained in the graphic products is supported and amplified by narrative and tabular data presented in this report. Collectively, these products satisfy the objective of providing basic resource information. They have served to introduce the principles and methods of resource surveys to the GRM, and they have immediate application in early 1977 decision processes.

- Counterpart scientists from the GRM participated in all aspects of the Dilly study and contributed significantly to the overall success of the project. The range analyses were performed by EarthSat team members, with assistance from Dr. C.E. Poulton (FAO, Rome) and Drs. P. Zinke and H. Heady of the University of California, Berkeley.

- Estimates of forage production based on dry season field surveys (reconnaissance level) proved to be more than 90 percent accurate as verified by post-rainy season field sampling. This is an important range management technique which has now been proved in the Dilly area.

Part II - Newlands Tsetse and Range Survey (Selection of Test Site for Control Operations)

- A reconnaissance level study was made of three Newlands candidate areas of Dioila, Monts Mandingues, and Kita, using LANDSAT imagery, aircraft visual observation, photo flights, and limited ground inspection. Maps showing the distribution of Land Units, covering over 2,179,000 hectares, were prepared as 1:200,000 scale overlays to LANDSAT imagery. These maps describe geomorphic, vegetation, land use, and soils characteristics of the three areas.

- Evaluation of the Newlands areas for tsetse eradication utilized the mapped information together with considerations of extermination techniques, existence of a defendable perimeter, economic justification (costs), and range production potential.

- The Kita study area was found to offer the greatest opportunity for range utilization through the elimination of tsetse infestations. The Kita study area also provides the greatest potential for further development of livestock production programs in the Newlands based on natural and cultural resources. Detailed studies of actual tsetse distribution and tsetse ecology must precede a progressive tsetse eradication program.

- Dr. K.J.R. MacLennan, consulting entomologist, was a principal contributor to the EarthSat team's Newlands analyses and conclusions.

- LANDSAT imagery, properly processed and analyzed, proved to be a useful tool in reconnaissance level studies of tsetse habitats. Key features of land use, green foliage, human habitation indicators and drainage networks, coupled with the knowledge of tsetse infestations in similar areas of western Africa, resulted in the detection of probable infestations in Newlands areas. This information provides a useful guide to essential ground surveys which are yet to be performed.

Part III - Training

- A one week training course was presented by EarthSat at the offices of OMBEVI, Bamako. Course subjects were:

1. Fundamentals of remote sensing, including discussions of theory and practical applications of satellite remote sensing to natural resources studies.

2. Basic principles and methodology of aerial photo-interpretation as utilized in the Dilly and Newlands studies. Emphasis was placed on geohydrology, geomorphology, and vegetation analyses.

3. An introduction to the principles of range management, with special attention given to the integration of aerial photography in range surveys. Although this training was originally intended for five OMBEVI personnel, the concurrent presentation of the AIDSAT demonstration in Mali resulted in an expansion of the EarthSat training course to include a total of 27 participants.

- Further training was provided in the course of the Dilly and Newlands field surveys and was coordinated with the classroom instruction. Two weeks of orientation and training for Dr. Sow of GRM was also provided in EarthSat's Washington laboratories.

Summary Statement

- The ultimate value of the training, photo maps, information overlays, and supporting data will be realized only through their use and application in planning, design, and implementation of projects. The products delivered under this contract are an important prerequisite to forthcoming Mali II programs, and contain significant information of value to agricultural and reforestation activities, range management planning, land use/capability surveys, water exploration projects, and related resource and infrastructure development programs. The graphic products, in particular, represent a base of information that can be used, added to and expanded as part of on-going and future development programs.

1. INTRODUCTION

1.1 GENERAL PROGRAM GOALS

The Government of the Republic of Mali is engaged in major programs for the development of livestock production and marketing. These programs include assessments and evaluations of range resources and their present utilization, upon which range improvement and range management programs may be developed and implemented. Such range improvement and management programs, in the context of recent Sahelian drought conditions, are designed to optimize range productivity, increase usable animal products, and improve the life of the pastoralists and the Malian agricultural community in general.

The Mali Livestock Sector Grant is an ongoing and continuing effort and is part of an international program to solve resources and human problems of the Sahel region. This region extends across West Africa, corresponding roughly to the Savanna region and continuing north to the sub-Saharan and Sahara Desert. It is a region of predominately nomadic and transhumant livestock grazing, with significant areas of land suitable for agricultural crop production for sedentary populations.

Recognizing the importance of improved resource information and the need for baseline resource studies upon which to begin land use development and management programs, Earth Satellite Corporation (EarthSat) has 1) prepared selected resource analyses and inventories; and 2) organized and mapped relevant resource characteristics and current conditions of these resources so the needs of land use planning, development, and management may effectively be addressed. The present project has two principal components, the Dilly project of the Sahel grazing activity and the Newlands activity project.

The Dilly study is a semi-detailed range site survey. The project area borders on the north at the Malian/Mauritanian frontier and encompasses an area of approximately 1,313,600 hectares in the Sahelian zone. A variety of analyses and range resources evaluations has been prepared, as well as mapped products at 1:50,000 scale.

The Newlands study is a reconnaissance level survey of range resources and tsetse fly habitats for these three study areas. These are located in the regions of Diolia (433,600 hectares), Mont Mandingues (349,400 hectares), and Kita (1,396,000 hectares), all of which are in the more heavily vegetated part of Mali and represents high value wooded grasslands and savannas in the Sudanian and northern Guinean zones. Maps have been prepared at 1:200,000 scale for each area.

It is our expectation that this report and its accompanying mapped products will become part of a growing body of knowledge that will contribute to improving land use decisions, development programs, and effective resource management activities in Mali.

Program Objectives

The present program undertaken by EarthSat for the Government of the Republic of Mali supports the Mali Livestock Sector Grant. The specific objectives are as follows:

1. By appropriate investigations utilizing interpretations of aerial photography and field surveys in conjunction with other available data, provide the Government of the Republic of Mali with basic information on land forms, soils, vegetation and range resources of the Dilly area for the purpose of:

    a. Planning design and implementation of an extensive grazing project in the subject area.

    b. Providing baseline resources data for use in subsequent evaluations of the ecological impact of project interventions.

2. By interpretation of digitally enhanced LANDSAT imagery combined with limited aerial and ground surveys by experienced scientists, provide the Government of the Republic of Mali with regional reconnaissance level resource information for the three Newlands project areas. The resource information includes assessments of ecological units, the range resource in tsetse fly habitats, and other information which is necessary to permit an informed choice among the three candidate areas as to which is best suited for further investigations for a tsetse fly eradication and rangeland development project.

3. To introduce principles and methods of range resource surveys to the Government of the Republic of Mali.

4. To provide preliminary training to a cadre of Government of the Republic of Mali technicians on the techniques and utilization of resource inventories through:

    a. Training in the principles of aerial photo interpretation and remote sensing technology; and

    b. direct iteration and participation in field and office procedures in both the United States and Mali.

This project has successfully met each of the above specific objectives. The data sources, analysis, and mapping procedures, and the preparation of various resource maps for both the Dilly project area and the Newlands project area are discussed in detail in Parts II and III, respectively. How the results of this study may be applied in Mali, and their implications for present and future programs in the Livestock Sector, are also presented. Part IV reports on the training course conducted in Bamako in October 1976.

2. DILLY RANGE SITE SURVEY

2.1 INTRODUCTION

The written and graphic products developed during the Dilly range survey were designed to provide the Government of the Republic of Mali Mali (GRM) with basic information which will enable it to plan and implement an expanded livestock production program in the Dilly area. Information based on vegetation, landforms, and soils was used as baseline data for the EarthSat resource inventory of the area and provides information for subsequently more intensive range surveys, and range management plans.

Survey Objectives

The objective of the EarthSat Dilly range survey is to provide the Government of Mali (GRM) with basic information on the soils and vegetation resources of the Dilly region of Mali for the purpose of:

a. Planning, design, and implementation of an extensive grazing project in the area.

b. Providing baseline data on soil and vegetation resources for use in subsequent evaluation of the ecological impact of project interventions (monitoring).

c. Providing an introduction to the principles and methods of resource surveys to GRM range scientists (i.e., through U.S. and on-site training).

EarthSat provided an interdisciplinary team of scientists possessing the capabilities necessary to conduct the required field surveys and to interpret corollary satellite imagery/photography and aerial photography required for a range analysis. This team, representing the professions of agronomy (soils), range management, biogeography, biology, botany, and geology, successfully interacted with their Malian counterparts during the field surveys to achieve this goal.

Data gathered for the objectives included the use of Skylab imagery, aerial photography, and field surveys, which were interpreted and exhibited as specifically interpretive and descriptive overlays for:

1) Ecological units
2) Burns
3) Drainages and Candidate areas for surface water development
4) Roads, trails, and villages
5) Range utilization

The information presented in these graphic products is explained and expanded upon by this technical report.

The project and contractual objectives were achieved using state-of-the-art satellite and aerial photographic interpretation, coupled with current U.S. Department of Agriculture range survey techniques. The survey was completed at the semi-detailed survey level.

Concepts of Range Surveys and Range Resources Management

Successful livestock production programs are based on three fundamental components and must be considered before development of management programs. They are:

1) Animals - The development of new livestock breeds, including breeding and husbandry for specific characteristics must be accomplished. Also, the general health of the animals must be considered, including control of animal diseases and parasites.

2) People - People are the driving force in any successful livestock production program. An incentive must exist for those involved in all phases of production, from the herder to the distributor of the final products. It is essential that they understand and be motivated to achieve those goals which are necessary to improve production and, at the same time, maintain or improve the resources necessary to carry out the programs.

3) Vegetation, Landform, and Soils - An understanding of the vegetation, landform, and soils and their interrelationship is essential in a successful and sustained livestock program. The impacts of grazing on vegetation, and the methods by which these impacts may be diminished must be understood and practiced. This is a single, fundamental, precept of range management.

The Dilly survey concerns itself with only one of the above components; Vegetation, Landform, and Soils. Information based on this component was obtained and mapped to provide a base for subsequent and more intensive surveys, and to provide data necessary to make broad decisions dealing with range resources.

Maintaining a productive range requires preservation and improvement of the entire range, while making maximum use of it to produce animal products. The use of basic range management practices has been tested and proved to be effective in minimizing the grazing impact in order to achieve this goal.

Each practice can be categorized and described; however, in effect, the science of applying these recommendations must be modified to fit the conditions of individual ranges. This can be done only by the managers directly involved in grazing livestock on a given area. For clarity, range management practices can be classified as follows:

Forage Management Practices

This group of practices is most important from the standpoint of maintaining and improving the desired range condition. It involves an understanding of the physiology, phenology, and ecology of the plants present. This knowledge must be translated into a grazing system where numbers of animals and seasons of use are taken into account in timing the range utilization.

There are many systems of grazing, each developed for a specified situation; however, it is better for the range technician to use local information and develop local systems for grazing plans. The range carrying capacity is a function of management and the methods by which a range is managed determine its carrying capacity. This applies only when management is specifically concerned with maintaining or improving the range. If management practices continue to deplete rangeland, there is no need for forage management practices, and they become a waste of money and effort.

Livestock Distribution Practices

These practices are common range management techniques. They are concerned with those methods which will properly distribute livestock over a given area. Such activities as stock water development (windmills and catchments), herding, and placement of salt are commonly used. The purpose of these practices is to obtain an equitable utilization of the range by proper livestock distribution through the training of herdsmen to graze their livestock where they normally do not. These practices present a hazardous potential for contributing to range depletion, if practiced without consideration of forage management practices, proper stocking rates, and season of use.

Forage Improvement Practices

This group of practices includes seeding; control of unwanted plants by mechanical, chemical and management means; and limited fertilization. These practices should not be used until the forage management practices, including a grazing plan and distribution practices, are in effect.

Forage improvement practices are expensive and provision must be made to protect treated areas from overgrazing until the new forage plants are established. However, when these practices are properly implemented, they can contribute significantly to improvement in overall livestock production.

Fertilization on dry land ranges has never been shown to be practically effective, except in those instances where there is sufficient money, ground moisture, and vegetation potential to support it, e.g., meadows and fertile bottomlands. Time and money should not be expended for range fertilization programs, unless research shows that the specific conditions are appropriate.

2.2 DILLY RANGE SITE SURVEY STUDY AREA: LOCATION AND DESCRIPTION

The Dilly range site is located approximately 275 kilometers north of Bamako. It is approximately 1,313,600 ha (13,136 square kilometers) in area, and is bounded by the 8°10' longitude in the west, 7°20' longitude in the east, the 14°30' parallel in the south, and the Mauritanian border in the north. Nara, which is served by a small airport, is 40 kilometers northeast of Dilly and approximately 30 kilometers east of the eastern border of the project area. Travel from Bamako via Kolokani and Falou, to Dilly requires one full day via a four wheel drive vehicle.

Climate

The climate in Mali is categorized as Guinean, Sudanian, and Sahelian and is affected by two sharply delineated seasons. These are:

- The wet season, which occurs from June to the end of October, with the greatest rainfall in late Summer.
- The dry season occurring from October to June, divided into a dry cold period from December to the end of February and a dry hot period from March to the end of May.

Rainfall in the Dilly area is low, with a long-term average of approximately 500mm. As in many African savanna zones, the rainfall occurrences are irregular and inaccurately predictable. The irregular rainfall can be as detrimental to range and crop production as low rainfall, in that irregular rainfall may not occur at optimum times for vegetation production. Much of the woody vegetation in the Dilly area was destroyed during the Sahelian drought.

The rainfall gradient increases from north to south across the Dilly site, with slightly higher precipitation occurring in the south. This increased rainfall, in conjunction with specific soil and geologic factors, is responsible for the more abundant and different vegetation associations in the southern part of the site.

Herding and Agriculture

Cattle herding and agriculture are the two most important activities of the region.

Grazing is both sedentary and migratory. Sedentary grazing systems find the cattle remaining in the vicinity of the owner's villages, unless forage or water shortages force migrations to other villages, grasslands, or water resources. Migratory grazing and the movement of people (transhumance) occurs out of the Dilly area to the north and south, at different seasons and for different purposes.

Northern transhumance, from Dilly to Mauritania, occurs principally to assuage salt needs of the cattle. The movement usually begins in July, at the beginning of the rainy season, or at first sowing. Approximately 80 percent of the cattle move north leaving 20 percent in the Dilly area. Return from the northern salt areas is initiated by the drying of the pools. These are relatively short, local migrations.

Southern transhumance differs from the northern moves in that entire families accompany the herdsmen. The migration time is longer and occurs at a different season. The migration taking place from November to June leaves approximately 40 percent of the cattle remaining in the area while the remaining 60 percent move south. People move south to locate water for their herds, new grazing lands, and to work during the dry season, and participate in the exchange of trade goods.

Migrating cattle normally remain in the Dilly area during October. Migrant cattle from Mauritania add to the grazing pressure in the Dilly area and often remain in Dilly from one to six months (Rupp, 1975).

Second in importance to cattle raising in Dilly, for economic and subsistence purposes, is agriculture. The chief crops are varieties of millet and sorghum, beans, peas, and peanuts. Cotton and maize are grown to a limited extent. The agriculture, for all practical purposes, is subsistence agriculture, although there may be some grain marketing, particularly in productive years (Rupp, 1975).

Geology and Landforms

The bedrock over most of central Dilly is Cambrian schist, however, Ordovician sandstone outcrops in the southern, eastern, and western portions of the area. Extensive parts of the Dilly study area are covered with recent aeolian sand.

The soils developed from the schist are lateritic. There is an argillic (clayey) horizon between the schist bedrock and the overlying recent aeolian sands.

The soils developed from sandstones are lithosols resulting from the initial weathering of the sandstone. With increased weathering, the lithosols grade into arenaceous (sandy) soils in the pediment areas.

The recent sand dunes are of two distinct ages. The older are longitudinal in form and are lateritized, and the younger are ripple-like and have had no laterization. These dunes occur in the northern, eastern, and central sections of the Dilly area.

Planar landforms occur mostly in the central and western portion of the Dilly site. Some are aeolian plains and sand sheets, others are denuded with little sand cover. Pediments and Inselbergs occur in the north and south with the most extensive association of these in the southeastern (Mourdiah) sector of the site.

There are two major "depressional" landforms in the Dilly area.

1) The Valley of the Serpents is the largest, and extends southwestward across the southern half of the area. It is fluvial in origin.

2) A large non-fluvial depression associated with a doleritic dike begins 15km west of Koronga and extends east-northeast out of the Dilly site.

Vegetation

In general, the vegetation trends from Sahelian in the north to Sahelian-Sudanian in the south. This is reflected in the change from predominantly shrubby microphyllous species such as Acacia spp. and Commiphora spp. in the north, to broad-leaf forms such as Sterculia spp. and Combretum spp. in the south.

2.3 DILLY RANGE SITE SURVEY METHODOLOGY

The Dilly range site survey methodology consisted of combined aerial photointerpretation and field studies. The project methodology followed the experiences of EarthSat resource scientists and standard ecological approaches to land use and range resource surveys.

The Dilly survey incorporated a series of tasks, beginning with familiarization of the area through field trips and continuing with collection of literary, cartographic, and aerial photographic information. This was followed by the actual photointerpretation, field verification of the interpretation, and field work including soils and vegetation sampling. The accomplishment of these tasks resulted in preparation of the maps which graphically convey accumulated data and information. The final task was the analysis of the results and the report preparation, including the annotation (using descriptive/interpretive legends) of aerial photographic and map products.

Acquisition and Use of Preliminary Information

Literature searches, including maps and aerial photographs, were the first step in the survey, and provided the team with basic ecological and land use information. During the initial stages, literature describing the Sahelian region was gathered from sources in the United States, Africa, and Europe. These sources included the U.S. Agency for International Development, the United Nations Food and Agricultural Organization offices in the United States, United Nations, and governmental and education libraries. Information describing the West African environment was obtained from institutions in the United States, the Institut Geographique Nationale (IGN) through OMBEVI in Bamako, and other overseas sources.

Topographic maps at a scale of 1:200,000 were obtained from IGN, Paris, and Bamako. These maps form the base reference documents for many of the cartographic products developed. Soils, vegetation, geologic, and other types of maps from the U.S. and French agencies also were obtained and used during the project.

Two series of aerial photographs was obtained from the IGN through OMBEVI in Bamako. These were color infrared stereo aerial photographs at a scale of 1:50,000, in 225 x 225mm format, printed on transparent film (positives), and black-and-white (panchromatic) stereo aerial photographs at 1:50,000 scale, dated 1975.

Color infrared satellite photography, acquired by the United States Skylab Manned Space Station, was obtained from the EROS Data Center, Sioux Falls, South Dakota, U.S.A. Two Skylab photographs encompassed all but the northwest quadrant of the Dilly range site and provided a synoptic view of the environment and serve as a base for the groundwater exploration map.

LANDSAT imagery of the Dilly site also was acquired from the EROS Data Center in Sioux Falls and provided regional information for groundwater and other environmental studies.

Interpretation Techniques

The primary interpretation technique used in the study was aerial photointerpretation. Photointerpretation was supported by available published map information, and on-site field studies.

Color infrared positive transparencies and the black-and-white prints at a scale of 1:50,000 were used for the interpretation. Although color transparencies provide the best image resolution, black-and-white prints are easier to use in the field, and provide entirely adequate detail. Duplicate sets of black-and-white photographs covering the Dilly area were made into a series of nine uncontrolled mosaics dividing the Dilly area into photomosaic maps of approximately 1,460 square kilometers each. These mosaics provide a synoptic view of the overall morphological relationships of the landform and vegetation patterns of the Dilly study area.

The interpretation of vegetation and landforms was accomplished by biologists and geologists working together as a team. The objective of their interpretations was to integrate vegetation/landform analyses into ecological units reflecting the interrelationships of the landforms, soils, and vegetation of the area. This was accomplished by using standard photointerpretation techniques, some of which are described below.

In any photo or image, objects are recognized by shape, size, color, and texture. Object patterns, shadows and topographic location provide additional recognition clues. Because of the relatively small scale of the photography, shadows, which are often important in tree species identification, were not of use.

Also utilized in the interpretation was stereoscopic viewing which creates a valuable illusion of three-dimensional size or volume; the landscape appears as it would be if the interpreter were viewing it from above. In effect, the stereoscopic view exaggerates relief of height, which is an advantage in photo-analysis, particularly in the relatively flat terrain of the Dilly study area.

In the vegetation analysis, large trees appear as small raised dots. In the villages, these are probably Ficus spp. for example, and Sterculia spp. in the savannas and plains. These are inferences drawn from ground truth and ecological knowledge of the region, since the size of the trees on the photos prohibits identification by the unique features of the plants themselves. Scattered shrubs and small trees are difficult to identify, especially in a savanna situation where in many instances they cannot be differentiated from the grasses. Shrub density (percent ground cover) contributes to subtle texture and tone changes perceived in the environments on the imagery, which permits an estimate of shrub

cover. Where shrubs or trees are abundant, their combined darker "tone signatures" contrast greatly with the lighter tones of the grasslands and identify them as predominantly shrublands or woodlands. Grasslands are recognized on the basis of a lighter tone (color) and smooth texture. Tone and texture are the two parameters most important where the geometric or associated landform clues are imperceivable.

Burns are difficult to interpret because they often modify or obscure standard vegetation and landform indicators. Burns are, however, valuable ecological indicators of environmental conditions as discussed in Section 2.4.

Agricultural lands, currently or recently in production, appear as light-colored, smooth-textured regions, square or rectangular in form. Abandoned or fallow croplands often are irregular in shape; sometimes dark in tone, and may be covered by small dark dots indicating revegetation by shrubs and/or small trees. Almost all recognizable villages or settlements are surrounded by agricultural land and there are definite agricultural patterns surrounding villages in relation to the different groups of people that inhabit the Dilly area.

Interpretation is closely tied with landform analysis. Plant species density and type vary with landform and soil moisture. Because different landforms contain soils of varying moisture-holding capacities, landforms were used for this important parameter to aid in the delineation of vegetation. For example, longitudinal dunes contain woodland (dark in tonal signature) in the swales between the dunes because water tends to collect in these depressions, resulting in a water table closer to the surface. As the dunal elevation increases, the soil moisture content decreases, with a consequent increase in the percent of shrub savanna.

Another example of landform contributing to vegetation analysis is the occurrence of woodlands in drainages or depressional areas. The wider and deeper the drainage channel, the greater the prominence of larger trees, for example, in the bottomlands of the Valley of the Serpents. A combined wooded area - wetland vegetation complex exists in the large depression at Koronga, and is quite obvious on the photographs. Other depressions may not support woodlands, but the denser vegetation growth and increased soil moisture provide a dark tone signature.

Photo-analysis of landforms is a powerful tool in range evaluation and was important in EarthSat's analysis of the Dilly study area. Landform analysis involves logic similar to that used in vegetation analysis. The five keys used in landform analysis, which eventually lead to the identification of landforms are:

- Topography
- Drainage
- Erosion
- Vegetation
- Tone

Using stereo photographs and stereoscopic viewing, every landform was identified by its own specific variation of these five keys.

Instrumental in the aerial analysis of a landform is its topography, and this was easily determined from analyzing photographs stereoscopically. The second key, drainage (consisting of gullies, tributaries, and major streams), is one of the more important characteristics of landform. Surface drainages originating on a landform reflect the characteristics of the landform, the most important of which is its permeability. A controlled drainage pattern, containing angular tributaries, may indicate a landform with shallow depth to bedrock.

The third key, erosion, is the most important direct clue used in the aerial photographic indication of soil texture. Soil texture reflects the size of the soil particles making up the soil body. Erosion, in the form of gullies, occurs in landforms where water initially collects as surface runoff, creating scars of soil removal. Because the characteristics of gullies (shape, cross-section, profile) are unique to specific soil textures, general soil type interpretation of the gullies on aerial photographs is possible.

The fourth key, vegetation, is of interpretive value in a general sense - that is, general vegetative types are specific to certain landforms.

The fifth key, photographic tone, is a valuable criterion when used judiciously with the four previous keys for landform interpretation. For example, a darker photographic tone is generally associated with terrain of higher moisture conditions, and soils having a greater clay or organic content. Lighter tones usually are associated with those landforms having a more coarse-texured soil profile.

Field Surveys

Field surveys and field checking of aerial photointerpretations are essential to a properly conducted project. Field surveys provide both familiarization and verification functions. These functions can be either briefly conducted trips through an area to verify photointerpretation, or lengthy expeditions including detailed field analysis procedures. Field surveys associated with the Dilly Range Site Survey combined elements of basic photointerpretation field checking, plus soils and vegetation analysis, principally conducted on the ground.

Field trips can be conducted both on the ground and from aircraft. Aerial field trips often are used for intitial familiarization with an area or to record photographically selected information to verify interpretation.

It is absolutely essential, especially in remote areas like the Dilly region, to be equipped properly to conduct field activities. Very generally, this includes consideration for mobilization of equipment, people, support services, and proper ground truth techniques and the activities of local scientist-counterparts.

Mobilization

Mobilization (logistics) includes acquisition, preparation and utilization of vehicles and camping equipment for field survey work. No details can be overlooked pertaining to transportation, such as types of vehicles, fuel and oil reserves, water, spare parts to be taken on the trip, and alternate possible local maintenance locations within the project area. The logistics may include the selection of supply caches that may have to be established at various locations in the field, prior to the actual journey.

Camp equipment and food supplies must also be selected carefully and organized prior to the field survey. It is best if every individual in the field team, from party chiefs to drivers, has enough equipment to be as self-sufficient as possible in order to expedite each day's activities. Food supplies should be adequate for the trip, but must be compact. Each man must have enough water for drinking, cooking, and bathing. It is not an understatement to say that this type of field camping is one of the most vital aspects contributing to the success of a field survey.

Ground Truth Techniques

Ground truth techniques in the Dilly project were designed to serve two purposes: 1) to expeditiously and effectively learn, and verify, landforms and vegetation patterns seen in the aerial photography, on site; and 2) to obtain soil samples and vegetation production estimates in sufficient quantity to be representative of the area and contribute to the resource inventory requirements.

Field surveys to Dilly by EarthSat teams were conducted in April and October of 1976. Field trips should be avoided during excessively hot or rainy seasons, unless circumstances dictate these climatic situations as particularly valuable for field data collection. Most often, field efforts are planned for weather when vegetation, crops, etc., appear as they do on the imagery, or at particular important vegetational growth periods. The April-October field activities enabled the field team to view the Dilly study area in both the dry season and immediately after the wet season.

All available and necessary maps and aerial photographs or photo-mosaics were taken to the field, because each contained information that complements or supplements the total overview. When possible, previously delineated information was drawn or photographically printed on the photos or photo-mosaics for field checking. It was preferable to have as much information as possible on one photo-base or map, since overlays become difficult to use in the field, and time and information are wasted when constantly trying to correlate overlays to photos. For this reason, EarthSat photo-reproduced the initial land cover and landform delineations on each of the nine Dilly mosaics and mounted the mosaics on cloth backing for durability. These mosaics were folded into compact size to facilitate their use in the field.

The key to verifying or correlating field information with photo interpreted information is accurate determination of precise ground locations. This is accomplished by finding the exact position on the photomap and by constantly monitoring travel direction and distance. This is difficult in savanna-like environments where frequent obvious "check points," such as unique vegetation formations, rivers, roads or buildings, are few, and the environment is uniform or homogeneous. While navigating in the field in the Dilly study area, direction of travel was continuously monitored by Brunton compass, and the distance between check points, usually villages and stopping points, was indicated on the vehicle odometer, recorded at each stop or position directly on the photo-mosaic. Notes and photos were recorded for each vegetation composition and soil type. Tape recording the notes greatly facilitates this activity. Vegetation production and soil samples were taken at "bench mark" environmental sites.

Reduction of raw field information consisted of first, deciding upon the final ecological unit designations for the vegetation associations and landforms observed in the field. These were then verified or corrected on the photo-mosaics. The extensive lists of plant species and soils types and their locations within the various ecological units were then reduced (by iterative process) to dominant plant species and key soil types existing within key ecological units.

Malian Counterpart Scientist Activities

The Malian counterpart scientists to EarthSat scientists were indispensible in the field surveys. They provided the EarthSat scientists with invaluable pedological, phenological, botanical and cultural infomation about the Dilly study area. Since place names in Mali often have environmental and cultural connotations in themselves the presence of Dr. Sow and Mr. Bah were quite valuable to project goals.

Production

In order to establish production estimates, vegetation samples were cut and weighed during the field trip of October 6-12, 1976, when full vegetative growth was complete and grasses had set seed in full maturity. Forty sample plots distributed through the Dilly study area were clipped and weighed to train the field team in estimating green weight production and in calibrating ocular estimating procedures, a standard practice in the United States. Sample plots were one meter square, and all clippings were air dried and weighed. Production estimates were corrected to an air dry basis as opposed to green or *in situ* weights. Additional sample plots were clipped and weighed by the field crews periodically to verify and calibrate ocular estimates.

Following the field data collection, production was determined for all vegetation associations found in each landform (i.e., production was determined for each ecologic unit). A further refinement of production was made on the basis of location within the Dilly study area. Two

zones, north/central and south, were identified. Annual rainfall and production are greater in the southern zones and become significantly less as the Mauritanian border is approached. For analysis purposes, the north/central zone consists of the following photo base map titles: Sanpaka, Farkeli, Koronga, Dali, and Dilly. The south zone includes: Bofonde, Dinyan, Falou, and Mourdiah. It should be noted that EarthSat's dry season field survey (April/May 1976) produced estimates of production which proved to be over 90 percent accurate, as verified by field sampling in October, 1976.

The accuracy of these production estimates illustrates the value of reconnaissance level information when it is utilized by trained range scientists. To develop this capability requires a considerable amount of field experience.

Availability of soil moisture is the limiting factor for plant growth in the Dilly project area. Information on seasonal inflow of moisture into the soil and corresponding moisture losses due to runoff, sub-soil percolation, and evapotranspiration is limited. However, since the native vegetation area is the expression of environmental forces, including available moisture, a relative rating for range sites can be established by studying the present vegetation, soils, and rainfall records. The main soil factors which require study are:

1. Depth to bedrock or restrictive layer affects root development and determination of the water available to plants. Generally, soils of aeolian landforms are rather deep. Soils of plateau and pediment landforms are often shallow, while soils on mid-slopes and valleys are moderately deep to deep. Depth of soils can be limited by a layer of lateritic gravel, which can be discontinuous or in an advanced state which is more continuous, and occurs from 50 to 250 cm below the surface. The restrictive layer can have a strong inhibiting effect on penetration of roots of woody species. When this layer is within 50 to 60 cm of the surface, such a situation favors grass with fibrous root systems over woody tap rooted species. This is one reason that pure stands of grass occur intermingled with savanna vegetation.

2. Soil texture is important for water holding capacity and its effect on root development. Soil textures in the Dilly study area are sand, silt, loam, and clay. Sands are low in water holding capacity, holding from 8.3 to 12.5 cm per meter of water per cm of soil. Loam has moderate water holding capacity of 12.5 to 25 cm per meter of water per cm of soil; silt, moderate to high of 25 to 33.3 cm per meter of water per cm of soil; clay, high of 33.3 to 37.5 cm per meter of water per cm of soil.

3. Soil structure describes the manner in which textural particles of the soil are arranged in definite patterns. This is important, especially for surface soil structure, from a permeability standpoint (the rate at which water enters and penetrates the soil). Three surface structures were observed in the Dilly study area.

   a. Single grain sands, which allow for rapid permeability.

   b. Platey or shingled structure. This occurs when overgrazing and cultivation have continued over a long period of time. It is associated with depletion of soil organic matter. Platey structure slows down the permeability rate.

   c. Massive or block structure. This occurs on playas and other areas where clay is exposed. Permeability is very slow with this type of soil structure.

4. Fertility is not of major importance on rangelands. With few exceptions, there is no practical or economical method of increasing soil fertility on dry land ranges in arid to semi-arid zones.

5. Water Holding capacity is the fifth soil characteristic. Sand holds about 12.5 cm per meter of water per cm of soil. Loam holds about 16.6 - 25 cm per meter per cm of soil. Clay holds about 33.3 to 37.5 cm per meter per cm of soil. There is a direct relationship in wildlands between available moisture and production. 2.54 cm of moisture will produce about 335.5 kilograms of vegetation per hectare.

Grass roots are 90 percent in the top 76.2 cm of soil or to the restrictive layer if less than 76.2 cm; therefore, the effective moisture for grass is in the first 76.2 cm or to the restrictive layer if less than 76.2 cm.

Example

A soil profile such as:

Sand 60.96 cm = 12.5 cm x 6.06 = 7.57 cm

Sandy loam 15.24 cm = 16.6 x .151 = 2.30 cm

9.87 cm

9.87 cm x 53.5 kg per cm = 1303.8 kg per hectare

It takes 20.32 cm of available moisture to grow a wheat crop. 20.32 cm x 53.50 cm = 1087.2 kg, or about the amount of vegetation produced by an acre of U.S. wheat in the 20.3 - 22.8 cm effective moisture zone.

Ground Photographs

On the following pages are selected photographs which illustrate specific site conditions found in the Dilly study area. These photographs were acquired during the field surveys and were an integral part to the overall Dilly range resources analyses, supporting the aerial photographic interpretation.

PHOTOGRAPHIC RECORD OF REPRESENTATIVE ECOLOGICAL UNITS FOUND IN DILLY AREA

Photo 2.1

A. Typical village located in Small Non-riparian Depressions, 1.12, within a Sandsheet and Plains landform, 1.41, and surrounded by grain crops, 510 (millet-sorghum).

B. Non-riparian Basins, 1.11, within Sandsheets and Plains landform, 1.41, between Dilly and Goumbou. Greener, more vigorous vegetation is seen in the depression in the background; Microphyllous Thorny Shrubland, 321, in foreground.

C. Non-Riparian Basin, 1.11, supporting Graminaceous-Cyperaceous Marsh, 316.

D. Slicks and Bare areas, 160, and Tall Shrub Savanna, 332, on dunes in Wide River Bottom with Floodplain and Terraces, 1.22, in the Valley of the Serpents.

E. Waterhole in Mixed Evergreen/Deciduous Woodland, 343, in the Bottomland of the Valley of the Serpents.

F. Dunes in the Valley of the Serpents supporting Tall Shrub Savanna, 332, transitioning to Tree Savanna, 331. The south bank of the Valley of the Serpents is seen in the distant background.

PHOTO 2.1

Photo 2.2

A. Mauritanian cattle migrating through Macrophyllous Non-thorny Shrubs, 326, on Sandsheets and Plains landform, 1.41.

B. Dry Season Deciduous Woodland, 342, in the Plains area, 1.31. Can be classified 321 Microphyllous when shrub cover is between 5 and 20 percent.

C. Tall Shrub Savanna, 332, on Sand complexes, 2.42. Sterculia spp. in background are in shrub form, but can grow to tree form, giving the area a 331, Tree Savanna environment.

D. Plateaus and Bench landforms, 2.32, in northwest Dilly, supporting Microphyllous Thorny Shrubs, 321, and Dry Season Deciduous Woodlands, 342, on the sandstone cap in the background.

E. Longitudinal Dunes, 2.43, with Tall Shrub Savanna, 332. Interdune swales have both tree cover and bare areas.

F. Overgrown, abandoned millet fields, 560.

PHOTO 2.2

2.4 MAPPING PRODUCTS

As described in Section 2.3, black-and-white aerial photographs were prepared as a series of nine uncontrolled mosaics dividing the Dilly site into photo mosaics of approximately 1,460 square kilometers each. These mosaics were each photographically reproduced on Cronaflex material for purposes of delineating various features. Cronaflex transparencies can be reproduced by Diazo processes. The mosaics are photo basemaps for the series of overlays that include Ecological Units, Drainage, Burns, Villages and Trails, and Range Utilization.

Photointerpretation was accomplished from the stereo pairs of color infrared and panchromatic aerial photos. Preliminary delineations were either drawn on the stereo pairs and transferred to the Cronaflex, or drawn directly on the mosaic in the same position as they appeared on the photos. Often, one aerial photograph could be matched with an area on the Cronaflex to produce a stereo image. Clear Cronaflex material was then placed over the delineated photo Cronaflex mosaics and the delineations were inked and annotated. The inked and annotated overlays were photographically reproduced in the required number of clear copies.

Ecological Unit Map

The ecological unit maps divide the Dilly region into discrete environmental units reflecting specific integrated vegetation and landform associations. These ecological units are based on the concept that vegetation generally reflects the unique environment occupied by each vegetational system. These unique environments are products of the vegetation patterns and soils as they are affected by the physical surface of the landscape. This relationship is expressed numerically in fractional legend form to reflect the natural association of land cover and land use (including village sites and agriculture) as currently existed.

Example -

$$\frac{\text{330 = Land cover and land use}}{\text{2.0 = Macro-relief and land form}}$$

Each category of land cover, land use, and land form was assigned a numeric symbol and a descriptive legend. These categories followed a hierarchical progression from the general to the specific in detail. Included in each ecological unit designator are symbols for estimated forage production and the area of that specific ecological unit. The ecological unit overlays provide a graphic view of the spatial distribution of the rangeland resources of the Dilly range site. The accompanying legend and detailed descriptions of the ecological units and the tabulations of their respective areas, provide the essential resource inventory information. A detailed description of the ecological units of the legend, the legend's development, and its compatibility to aerial photographic interpretation techniques is included in Appendix D.

Villages and Trails

The location of villages and trails were delineated on clear overlays at a scale of 1:50,000. Locations and names were taken from existing maps and data. IGN 1:200,000 topographic maps were used as supplementary information sources.

Drainage Delineation

Stream courses were delineated on 1:50,000 scale black-and-white photo mosaic basemaps. Channel locations were identified through monoscopic and stereoscopic viewing of black-and-white and color infrared aerial photographs. Stream channels were delineated on the basis of their size and contribution to larger drainage systems, which are considered to have a potential for surface water development. The channels delineated on the photography are considered to be ephemeral streams, i.e., those which flow only during and immediately after rainfall and receive little or no contribution to their flow by groundwater movement. Sites of potential surface water development include: 1) the confluence of one or more tributaries; 2) natural depressions where surface water might be collected; and 3) playas. These sites are indicated by shading on the photo basemap drainage overlay.

Playas were identified on the black-and-white aerial photographs by their characteristic dark toned signature and their unusual deranged drainage pattern formed by the alternate wetting and drying of these basins.

Existing trails radiating from villages, often follow drainage channels, and the villages themselves are almost always located in depressional areas. Channels containing trails were delineated where a well defined stream bed and bank could be identified, and depressional areas around villages were delineated in those areas where obvious surface water accumulation occurs.

Range Utilization

A series of range utilization overlay maps was prepared as clear film overlays corresponding to each of the 1:50,000 scale photo basemaps for the Dilly study area. The maps were prepared using analysis of 1:50,000 aerial photographs covering the Dilly study area, combined with detailed field observations in both the dry season (April, May), and post wet season (October).

Range utilization refers to the estimated percent of the current year's vegetation growth consumed by animals, either domestic or wildlife. Three degrees of utilization were mapped in the Dilly study area as shown on the overlays: Light (F) indicates 0 percent to 25 percent use. In this case, only a portion of the most palatable forage is consumed annually. Plant litter is present, but does not constitute a significant portion of the livestock diet.

Moderate (M) indicates 25 percent to 60 percent use. All palatable forage is utilized to some extent and a patchy grazing pattern is apparent. Plant litter is present in small amounts, but this is evident only from careful ground inspection.

Heavy (I) indicates over 60 percent use. All palatable forage is heavily grazed, and most of the less palatable plants are grazed in varying degrees, depending upon local livestock use. Bare soil is predominant, and almost all plant litter is lacking. Heavy use is apparent from aerial observation.

Burns

Areas were delineated which have been most recently burned. Recent burns appear black on both black-and-white and color infrared aerial photographs which were utilized for range management investigations. Older burns appear as light gray on black-and-white aerial photographs. The burns' signature, i.e., the tone and texture displayed on the aerial photograph, is dependent upon the presence or absence of charred residues on the ground and the degree to which a burned area has recovered vegetative cover. When a fire begins in a given area, it spreads until available fuel (i.e., vegetation cover) has been consumed, or a natural or man-made fire break is reached. Fire breaks such as stream channels or trails, are the most common types found in the Dilly area, although some fire breaks have been constructed in the area and others are planned. The identification of dark areas on photographic images as recently burned areas is often enhanced by the presence of linear boundaries along the edge of the burn formed by natural and man-made fire breaks.

Regional Groundwater Exploration Guidemap

An important factor in regional development in rainfall deficient areas is the location and development of groundwater resources. Interpretation of satellite imagery, with its consistent sun angle and its quasi-orthographic nature, provides valuable information on geologic structure (especially fractures and faults), lithology, (rock type identification), geomorphology, and vegetation relationships. This information, when combined with available regional geologic, topographic, and hydrologic data, enables the construction of a Groundwater Exploration Guide Map.

Groundwater Exploration Guide Maps produced from satellite imagery or photography should be used at a reconnaissance level. Areas selected from satellite imagery, which seem to have potential for groundwater resources, should be studied in more detail using available larger scale stereo aerial photographs. Finally, promising areas delineated on these aerial photographs should be verified in the field.

Groundwater Exploration Guide Maps produced from satellite photography at the initial reconnaissance level thus eliminate much of the region having little potential for groundwater, thereby focusing attention

on those areas that are most favorable. This reduces the cost of a ground based regional groundwater exploration program because it minimizes the necessary subsequent interpretation of aerial photos and costly field efforts.

A fracture analysis exploration guide map for the Dilly region of Mali was prepared from the interpretation of Skylab photography. This analysis could be performed only in those portions of the Dilly project area which contain Skylab coverage. Photography was interpreted by EarthSat geologists for structural (fractures and faults) and lithologic information using both, 1:100,000 and 1:200,000 scale image enlargements. The final map product is presented as an overlay to 1:200,000 scale images.

Landforms which have a relatively high permeability and which influence the movement and concentration of surface and subsurface water are potential acquifers. Conventional aerial photographic interpretation techniques utilize the combination of certain features noted on the photographs to identify specific landforms. These techniques can be applied to the interpretation of landforms, and specifically permeable landforms, from satellite imagery. In the Dilly region, two lithologies, the Cambrian schist, and the Ordovician sandstone predominate. Sandstone is considered to be the more permeable rock type.

Fracture and fault zones are generally more prolific water producers than surrounding areas, and where intersections of two or more fractures occur, the potential water yield greatly increases. Experience has shown that many of these lineaments are overlooked during ground investigations or standard aerial photographic studies, but can be observed from satellite imagery. Lineaments have been delineated on the map overlay to the Skylab photography. Many of these lineaments, even though they are covered by deep deposits of sand visible on the photographs, would be quite difficult to locate strictly through typical field studies.

Dr. A. Sow, of SOTUBA, and field surveys verified that groundwater obtained from fractures or faults in the schist region is usually very saline, but it may be potable for cattle and possibly for man. Where the schist rock lies at greater depths, the water in hand-dug wells is potable; here the water occurs in the soils above the relatively impermeable argillic horizon above the schist. In this case, where the source of water is primarily rainfall, acquifer recharge capabilities are undependable, especially during the onset of the dry season.

Dr. Sow described wells derived from the sandstone as having "sweet" water. Many of the villages are located along the boundary between the sandstone and the schist, and there the water is of fair quality, depending upon how fortunate the villagers were in their choice of well sites.

Lineaments, and especially those lineaments which intersect and are considered to traverse predominantly sandstone regions, are emphasized on the Groundwater Exploration Guide Map. Because of greater permeability

of sandstone rock and because of generally fresher water issuing from wells located in sandstone in the Dilly region, these areas should be considered the most favorable for further analysis using aerial photographs and ground studies. Examination of aerial photographs in those favorable areas defined on the Groundwater Exploration Guide Map must be accomplished before ground crew investigations commence.

2.5 RESULTS OF THE DILLY ECOLOGIC RANGE SITE STUDY

Photointerpretation, field work, and mapping resulted in a description of selected ecological units of the Dilly study area, complemented by photomosaics and resource and cultural information overlays. Used together, these written and graphic documents provided basic information for the resource inventory of the Dilly range site.

This section, Descriptive Information - Ecological Units, Dilly Study Area, describes the ecological units in hierarchical order by landform. Each landform is discussed in terms of its position in the environment, macro-relief, soils type, vegetation associations existing on the landform, and estimated forage production of the respective vegetation association. Soils descriptions are in both the United States and French soils classification systems. The ecological unit overlays are the primary map products complementing the description of the ecological units of the Dilly Range Site.

Landforms, vegetation associations, and forage production estimates are presented in the Descriptive Information - ecological units are summarized in Table 2.1. Area tabulations of these land cover/landform units are included in Tables 2.2 through 2.4.

TABLE 2.1
SUMMARY OF DESCRIPTIVE INFORMATION - ECOLOGICAL UNITS

Landform	Estimated Forage Production kg/ha		Vegetation Associations	Dominant Species
.10 Depressional non-riparian				
1.11 Basins without external drainage usually with playas or lakes				
1. Outer zone - from middle point of depression	1100	311	Annual grassland	Acacia nilotica
		321	Microphyllous thorn shrub	Acacia seyal
		323	Mixed microphyllous/macrophyllous shrub	Bauhinia rufescens Panicum laetum
		326	Non-thorny macrophyllous shrub	Schoenefeldia gracil
		332	Tall shrub savanna	
2. Middle zone - from lower point of depression to outer zone	1700	343	Mixed evergreen/deciduous woodland	Anogeissus leiocarpus (deciduous) Mytragina inermis (evergreen) Feretia canthoides Cyperus spp. Echinochloa colonum
3. Internal zone of depression may be absent	1300	316	Graminaceous/cyperaceous in depressions and bottomlands	Cyperus spp. Ipomoea aquatica Oryza barthii Panicum spp. Vetiveria higratana
1.12 Small depressional areas	1000-1300	510	Croplands	Millet and Sorghum
		560	Fallow or abandoned croplands	
1.20 Bottomlands				
1.21 Stringer or narrow bottomlands, limited terraces	1200	343	Mixed evergreen/deciduous woodland	———
1.22 Wide river bottoms with floodplains and terraces	———			———

TABLE 2.1 Continued

	Landform	Estimated Forage Production kg/ha		Vegetation Associations	Dominant Species
1.	Terrace	2300	311 331	Annual grassland Tree savannas	Bombax costatum Sclerocarya birrea Cassia mimosoira Sterculia setigeria Eragrostis tremula
2.	Top of dune (wind deposited landform in bottomland)	1900	323 326 332	Mixed macrophyllous/microphyllous shrub Non-thorny macrophyllous shrub Tall shrub savanna	Acacia senegal Combretum ghasalense Loudetia togoensis Schoenefeldia gracil
3.	Swale of dune (wind action)	3400	343	Mixed evergreen/deciduous woodland	Anogessius leiocarpus Mytragina inermis (evergreen) Ziziphus maurita (evergreen) Acacia senegal (deciduous) Acacia seyal (evergreen) Grewia bicolor (deciduous) Cassia tora Cyperus rotundus Echinochloa colonum
4.	Slicks	100	160	Bare areas	Balanites aegyptica Borreria radiata Irginea nigritana Mitrocarpus scaber
.30	Planar Surfaces				
1.31	Plains				
1.	Northern zone - 1-2 meters of soil over schist	1600	311 326 332	Annual grassland Non-thorny shrub Tall shrub savanna	Combretum ghasalense Commiphora africana Sclerocarya birrea Diheterpogon hagerup Elyonurus elegans Eragrostis tremula

TABLE 2.1 Continued

Landform	Estimated Forage Production kg/ha	Vegetation Associations	Dominant Species
2. Northern zone - less than 1 meter of soil over schist	600	311 Annual grassland 321 Microphyllous thorn shrub	Acacia seyal Eragrostis tremula Schoenefeldia gracilis.
3. Southern zone - 2 meters of soil over schist	2800	332 Tall shrub savanna 333 Mixed tree shrub savanna 342 Dry season deciduous woodland	Bombax costatum Sterculia setigera Combretum ghasalense Entada africana Sclerocarya birrea Cochlospermum tinctorun
2.32 Plateaus and Benches			
1. Northern zone - gravelly rocky soil, generally over sandstone. Weathered laterite may be exposed. Soil contains silt and clay.	1000	160 Bare ground 311 Annual grassland 326 Non-thorny macrophyllous shrub 332 Tall shrub savanna	Combretum ghasalense Pterocarpus lucens Hicrochloa indica Pennisetum pedicellatum Schoenefeldia gracilis Zornia glochidiata
2. Southern zone - gravelly rocky soil. Generally over sandstone. Weathered laterite may be exposed. Soil contains silt and clay.	1600	160 Bare ground 311 Annual grassland 326 Non-thorny macrophyllous shrub 332 Tall shrub savanna 342 Dry season deciduous woodland	Combretum ghasalense Combretum microuthum. Pterocarpus lucens Elyonurus elegans Fimbristilis squarosa Loudetia togoensis Microchloa indica Schoenefeldia gracilis
2.33 Pediments with inclusions of inselbergs			
1. Northern zone	800	326 Non-thorny macrophyllous shrub 332 Tall shrub savanna (soils high in clay and silt)	Combretum ghasalense Pterocarpus lucens Aristida mutabilis. Hicrochloa indica Pennisetum pedicellatum Schoenefeldia gracilis Zornia glochidiata

TABLE 2.1 Continued

Landform	Estimated Forage Production kg/ha	Vegetation Associations	Dominant Species
2. Southern zone	1300	326 Non-thorny macrophyllous shrub 332 Tall shrub savanna 342 Dry season deciduous woodland (soils high in silt and clay)	Combretum ghasalense Combretum microuthum Pterocarpus lucens Andropogon pseudapricus Elyonurus elegans Eragrostis tremula Fimbristilis squarosa Loudetia togoensis Microchloa indica Schoenefeldia gracilis
.40 Aeolian Landform System			
1.41 Sandsheets and plains			
1. Sandy soils - high in silt and clay (northeast quarter)	1200	311 Annual grassland 321 Microphyllous thorn shrub	Acacia nilotica Acacia seyal Bauhinia rufescens Aristida mutapilis Panicum laetum Schoenefeldia gracilis
2. Remainder of work area - northern zone southern zone	north-800 south-1500	326 Non-thorny macrophyllous shrub 332 Tall shrub savanna (sandy soils) 342 Dry season deciduous woodland 311 Annual grassland 332 Tall shrub savanna 326 Non-thorny macrophyllous shrub	Sterculia setigera Combretum ghasalense Guiera senegalensis Sclerocarya birrea Aristida mutabilis Eragrostis tremula Schoenefeldia gracilis
3. Soils with high silt and clay content at surface	100+	160 Bare ground (slick areas)	Balanites aegyptica Borreria radiata Mitrocarpus scaber Urginea nigaitana

TABLE 2.1 Continued

Landform	Estimated Forage Production kg/ha	Vegetation Associations		Dominant Species
2.42 Sand complex (knob-like hills and ripples of white sand with associated depressions)				
1. Northern zone	north-800	311	Annual grassland	Sterculia setigera
		321	Microphyllous thorn shrub	Acacia nilotica
		323	Mixed microphyllous/macrophyllous shrub	Acacia seyal Combretum ghasalense
		326	Non-thorny macrophyllous shrub	Sclerocarya birrea
		332	Tall shrub savanna	Aristida mutabilis
		333	Mixed tree/shrub savanna	Diheteropogon hagerupii
		342	Dry season deciduous woodland	Eragrostis tremula
Southern zone	south-1200	311	Annual grassland	
		331	Tree savanna	
		332	Tall shrub savanna	
		333	Mixed tree/shrub savanna	
		342	Dry season deciduous woodland	
2.43 ERGS				
1. Northern and central zone erg				
a. convex portion top of dune	1300	311	Annual grassland	Combretum ghasalense
		321	Microphyllous thorn shrub	Sterculia setigera
		332	Tall shrub savanna	Sclerocarya birrea Aristida stipoides Cenchrus biflorus Eragrostis tremula
b. concave portion valley between dunes	1200	326	Non-thorny macrophyllous shrub	Combretum ghasalense Sclerocarya birrea Schoenefeldia gracilis

TABLE 2.1 Continued

	Landform	Estimated Forage Production kg/ha		Vegetation Associations	Dominant Species
2.	Southern zone - rolling dunes not as pronounced	1900	332	Tall shrub savanna	Bombax costatum (deciduous)
			333	Mixed tree/shrub savanna	Sclerocarya birrea (deciduous)
			342	Dry season deciduous woodland	Combretum ghasalense (evergreen)
					Entada africana
					Sterculia setigera (deciduous)
					Terminalia avicennoides
					Andropogon gayanus
					Cassia mimosoides
					Coclospermum tinctorum
					Diheteropogon hagerupii
					Elyonurus elegans
					Eragrostis tremula

.10 DEPRESSIONAL NON-RIPARIAN

.11 Basins with Interior Drainage Usually Having Playas or Lakes

Position: These landforms occupy depressions between the dune formations, or occur along depressional fault lines such as the fault running southwest from Girel to Karonga. They are characterized by a lack of external drainage and occur in the northeast one-fourth of the project work area.

Macro-relief: Generally, this landform is flat, but undulating to rolling lands (such as recent sand dune deposits) can occur within the depressional areas.

Soils: Hydromorphic - These are soils whose development and characteristics (presence of gley and/or pseudo gley in at least one of their horizons) are influenced by permanent or seasonal water-logging. The surface soils are sandy, with a variable depth to clay.

Considerable amounts of alluvial clay, silt, and sand occur in these soils, giving the soil a muddy color. Clay occurs at varying depths, and when it is near the surface, playas form, especially during the wet season. Because these soils contain clay and silt particles and because of their depressional position, the soil moisture is better than that of the surrounding sand plains.

Textural Profile:		
	0-30 cm	Sand
	30-75 cm	Sandy Loam
	75-125 cm	Fine Sandy Loam
	125-150 cm	Clay Loam

Vegetation: The vegetation of the depressional areas (landform 1.11) is broken into three categories.

1. The outer zone of the depression - This area is characterized by soils with sandy surfaces. The vegetation associations are annual grasslands (311) microphyllous thorn shrub (321), mixed macrophyllous-microphyllous shrub (323), macrophyllous non-thorny shrub (326) and tall shrub savanna (332), represented by the following species:

    a. Shrubs

    Acacia nilotica
    Bauhinia rufescens
    Acacia seyal

b. Grasses

Panicum laetum
Schoenefeldia gracilus

2. Middle zone - The soils of this zone have a sandy surface with the subsoil containing varying amounts of silt and clay. Soil moisture is good, resulting in a mixed evergreen/deciduous woodland (343). Typical vegetation of this zone includes:

a. Trees

Anogeissus leiocarpus
Mytragina inermis

b. Shrubs

Feretia canthoides

c. Grasses

Cyperus spp.
Echinochloa colonum

3. Internal zone - This zone is wet during the rainy season and dry at other times. Because the soil is high in silt and clay particles, water infiltration is slow. The typical species are herbaceous (316).

Cyperus spp.
Ipomoea aquatica
Nymphaea lotus
Oryza barthii
Panicum spp.
Vetiverias higratana

Production: Kg/ha air dry weight
Outer zone - 1300 Kg/ha
Middle zone - 1700 Kg/ha
Internal zone - 1100 Kg/ha (seasonal production during inundation by summer rains)

.12 Small Depressional Areas

Position: These areas are usually smaller than those found in landform .11 and occur near, or at, the villages.

Macro-relief: Slightly depressional and flat.

Soils: Some alluvial action is evidenced, but not to the extent found in landform .11. The soils contain less clay and silt than landform .11.

Vegetation: These small depressional areas normally are occupied almost exclusively by agricultural crops.

Production: 1000-1300 Kg/ha. (Low)

.20 BOTTOMLAND RIPARIAN

.21 Stringer or Narrow Stream Bottom (Limited Terrace)

Narrow water courses with intermittent flows. Existing vegetation species growing adjacent to respective water courses may become denser within the depressional area of the stream. If not already a component plant association in the area, mixed evergreen/deciduous woodland (343) species may become dominant. An example of a narrow stringer bottom is the old stream which flows along the migration route from Bofonde to Doubala.

.22 Wide River Bottoms With Floodplains and Terraces

Position: The wide river bottoms are best illustrated in the work area by the Valley of the Serpents. There are no permanently flowing rivers in the Dilly work area, only intermittent water courses.

Macro-relief: Flatland.

Soils: The Valley of the Serpents presently is covered with alluvium varying in depth from a few centimeters to several meters. Beneath the alluvium, lies a heavy textured clay soil. These soils have a good water holding capacity and are capable of high production.

Textural Profile:		
	0-25 cm	Sand
	25-50 cm	Loam
	50-100 cm	Clay Loam
	Over 100 cm	Clay

Vegetation: Four topographic forms occur within the wide river bottoms which produce different types and amounts of vegetation.

1. Terraces - Includes the first bench above, and paralleling, the river bottom on either/or both sides. The vegetation is annual grassland (311) and tree savanna (331) with the following predominent vegetation:

a. Trees

Bombax costatum
Sclerocarya birrea

b. Shrubs

Cassia mimosoides
Sterculia setigeria

c. Grasses and Forbs

Eragrostis tremula

2. Tops of dunes within the wide river bottom. The vegetation association in this landform is mixed macrophyllous-microphyllous shrub (323), macrophyllous non-thorny shrub (326) and tall shrub savanna (332).

a. Shrubs

Acacia senegal
Combretum ghasalense

b. Grasses

Loudetia togoensis
Schoenefeldia gracilis

3. Swale between dunes - The vegetation of this area is a mixed evergreen/deciduous woodland (343).

a. Trees

Anogeius leiocarpus
Mytragina inermis
Ziziphus maurita

b. Shrubs

Acacia seyal
Grewia bicolor
Cassia tora

c. Grasses and Sedges

Cyperus rotundus
Echinochola colonum

4. Slicks - Areas of high silt and clay content. Very sparse vegetation is produced (160). The predominent species are:

Balanites aegyptica
Borreria radiata
Irginea nigritana
Mitrocarpus scaber

Production on the four respective topographic forms are in Kg/ha air dry weight:

Terraces - 2300 Kg/ha
Top of dune - 1900 Kg/ha
Swale of dune - 3400 Kg/ha
Slicks - 100±

.30 PLANAR SURFACES

.31 Plains:

Position: This landform is flat, generally overlying schist bedrock.

Macro-relief: Flat.

Soils: Haplustalfs (Ferric Luvisols): These reddish soils have a gradual argillic (clay) horizon, and are not saturated with water at any period. They have no duripan (restrictive hard layer) within one meter of the surface. These soils have a pallid (low in organic matter), or sombric (organic matter at least 1%) A horizon. There is no plinthic horizon within 125 cm of the surface. These residual soils, formed from the weathering of schist, vary from 1 to 2 meters in depth over the parent material. They have a more developed profile and contain more clay and silt and less sand than soils developed from sandstones or granites in this area of Mali. The texture of the subsoil is typically a clay loam. The moisture holding capacity in the root zone is good, and they are well drained.

Textural Profile:

0-30 cm	Sand
30-75 cm	Sandy Loam
75-100 cm	Loam
100-135 cm	Clay Loam
Greater-135 cm	Bedrock (Schist)

Vegetation: The plains landform is divided into three distinct vegetation and production units.

1. Northern zone with deep soils (1-2 meters) over schist - This area supports an annual grassland (311), non-thorny macrophyllous shrub (326) and tall shrub savanna association (332) with the following species:

   a. Shrubs

      Combretum ghasalense
      Commiphora africana
      Sclerocarya birrea

   b. Grasses

      Diheteropogon hagerupii
      Elyonurus elegans
      Eragrostis tremula

2. Northern zone with shallow soils (less than 1 meter) over schist which produces annual grassland (311) and microphyllous thorn shrub associations (321).

   a. Shrubs

      Acacia seyal

   b. Grasses

      Eragrostis tremula
      Schoenefeldia gracilis

3. Southern zone with a deep soil (1-2 meters) over schist. This area supports either a tall shrub savanna (332), mixed tree shrub savanna (333) or a dry season deciduous woodland (342) depending on the combination of species in the vegetation composition.

   a. Trees

      Bombax costatum
      Sterculia setigera

   b. Shrubs
      Combretum ghasalense
      Entada africana
      Sclerocarya birrea

   c. Grasses

      Coclospermum tinctorum
      Diheteropogan hagerupii
      Elyonurus elegans

Production: Kg/ha
Northern zone deep soil - 1600 Kg/ha
Northern zone shallow soil - 600 Kg/ha
Southern zone deep soil - 2800 Kg/ha

.32 Plateaus and Benches

Position: This landform occupies an upland position. Benches or table-tops occur as a result of the weathering of sandstone formations.

Macro-relief: Flat to rolling relief except where interrupted by abrupt escarpments facing the benches.

Soils: Entisols (orthents or psamments), Lithosols. These are shallow soils having little profile development. They may have a loamy very fine sand or even finer in the subsoil. Coarse elements and rock may be encountered at a shallow depth. Agricultural value of these soils is low, but they can be forested when the climate allows.

Textural Profile:		
	0-75 cm	Sand
	75-100 cm	Sandy Loam
	100-135 cm	Loam
	Greater-135 cm	Bedrock (Sandstone)

Vegetation: This landform is broken into the northern and southern zone. Weathered laterite may be exposed, and considerable amounts of silt and clay can occur in localized areas.

1. Northern zone - The vegetation associations of this zone are annual grasslands (311), non-thorny macrophyllous shrub (326), tall shrub savanna (332), depending on the combination of vegetation.

   a. Shrubs

      Combretum ghasalense
      Pterocarpus lucens

   b. Grasses

      Aristida mutabilis
      Hicroehloa indica
      Pennisetum pedicellatum
      Schoenefeldia gracilis
      Zornia glochidiata

2. Southern zone - The vegetation associations found in this zone are annual grasslands (311), non-thorny macrophyllous shrub (326), tall shrub savanna (332), or dry season deciduous woodland (342).

a. Shrubs

Combretum ghasalense
Combretum microuthum
Pterocarpus lucens

b. Grasses

Elyonurus elegans
Fimbristilis squarosa
Loudetia togoensis
Microchloa indica
Schoenefeldia gracilis

Production: Kg/ha air dry weight
Northern zone - 1000 Kg/ha
Southern zone - 1600 Kg/ha

.33 Pediments (With Inclusion of Inselbergs)

Position: These are eroded (usually sandstone) formations which form topographic highs, and which are surrounded by flat, to rolling, colluvial debris derived from the denudation of the Inselbergs.

Macro-relief: Undulating to hilly.

Soils: In general, the soils are Lithosols derived from eroding sandstone knobs. The colluvium on the surrounding pediment is rocky, sandy, or, if formed by water, it may contain some fine textured soils. In the case of the Dilly work area, these are young soils with the sandstone parent material in various stages of weathering.

Vegetation:

1. Northern zone - Vegetation associations found on this zone are non-thorny macrophyllous shrub (326) and tall shrub savanna (332).

a. Shrubs

Combretum ghasalense
Pterocarpus lucens

b. Grasses

Aristida mutabilis
Hierochloa indica.
Pennisetum pedicellatum
Schoenefeldia gracilis
Zornia glochidiata

2. Southern zone - Vegetation associations are non-thorny macrophyllous shrub (326), tall shrub savanna (332), or dry season deciduous woodland (342).

a. Shrubs

Combretum ghasalense
Combretum microuthum
Pterocarpus lucens

b. Grasses

Andropogon pseudopricus
Elyonurus elegans
Eragrostis tremula
Fimbristilis squarosa
Loudetia togoensis
Microchloa indica
Schoenefeldia gracilis

Production: Kg/ha air dry weight
Northern zone - 800 Kg/ha
Southern zone - 1300 Kg/ha

.40 AEOLIAN LANDFORM SYSTEM

.41 Sand Sheets and Plains

Position: This landform lies in inter-dunal areas, generally in the eastern half of the work area.

Macro-relief: Flatlands.

Soils: Quartzipsamments (Brown soils of arid or semi-arid tropical regions on loose sediments). These white to gray soils are coarser than a sandy loam texture and have a clay content less than 15 percent. These soils contain more fine textured soils than landform .42, and they show some effects of alluvial action. Water retention is low.

Textural Profile:		
	0-30 cm	Sand (single grain)
	30-75 cm	Sand with small amount of silt
	75-150 cm	Fine Sandy Loam

Vegetation: Sand sheets and plains - This landform is broken into two zones.

1. Northeast quarter of the work area, roughly the region from Goumbou to Dilly to Farkeli. The vegetation associations found in this area are annual grasslands (311) and microphyllous thorn shrub (321).

    a. Shrubs

        Acacia nilotica
        Acacia seyal
        Bauhinia rufescens

    b. Grasses

        Aristida mutabilis
        Panicum laetum
        Schoenefeldia gracilis

2. Remainder of the work area - The vegetation associations which occur are annual grasslands (311), non-thorny macrophyllous shrub (326), tall shrub savanna (332), and dry season deciduous woodland (342).

    a. Trees

        Sterculia setigera

    b. Shrubs

        Combretum ghasalense
        Guiera senegalensis
        Sclerocarya birrea

    c. Grasses

        Aristida mutabilis
        Eragrostis tremula
        Schoenefeldia gracilis

3. Scattered throughout this landform (1.41) are slicks or bare areas where the silt and clay are on the soil surface. Sparse vegetation consists of:

    Balanites aegyptica
    Borreria vadiata
    Nitrocarpus scaber
    Urginea nigritana

Production: Kg/ha air dry weight
Northeast quarter of area - 1200 Kg/ha
Remainder of area - 1900 Kg/ha
Slicks - 100±

.42 Sand Complex (Knob-like Hills and Ripples of White Dunes with Associated Depressions)

Position: Most of these dunes occur in the eastern half of the work area, however, some are found in the western part. These dunes have a complex landscape pattern, almost without a pattern.

Macro-relief: Undulating.

Soils: Quartzipsamments (Brown soils of arid and semi-arid regions on loose sediments). These soils are coarser than sandy loam, have a clay content less than 15 percent, and they have low levels of organic matter. Pedologically these soils are young, for the soil forming processes have not yet resulted in the formation of genetic horizons. There is no lithic contact within 50 cm of the surface. They are not permanently saturated with water. The parent material is aeolian sand often deposited from the reworking of landform .43. These dunal soils are white in color and low in fertility. The moisture holding capacity of the convex portion of the dune is low, less than 2.5 cm per meter of soil. The concave portion of the dune has better moisture holding and retention properties due to an accumulation of fine soil at about 125 cm.

Textural Profile:

Convex		Concave	
0-50 cm	Coarse Sand	0-30 cm	Sand
50-75 cm	Fine Sand	30-75 cm	Sandy Loam
75-150 cm	Fine Sandy Loam	75-125 cm	Loam

Vegetation: Seven vegetation associations occur on this landform differing slightly in vegetation association and productivity from north to south. These vegetation associations are listed below with their north and south distribution indicated by the letters N and S. Annual grasses (311) NS, microphyllous thorn shrub (321) N, mixed macrophyllous/microphyllous shrub (323) N, non-thorny macrophyllous shrub (326) N, tree savanna (331) S, tall shrub savanna (332) NS, mixed tree/shrub savanna (333) NS, and dry season deciduous woodland (342) NS.

a. Trees

Sterculia setigera

b. Shrubs

Acacia nilotica
Acacia seyal
Combretum ghasalense
Sclerocarya birrea

c. Grasses

Aristida mutabilis
Diheteropogon hageurupii
Eragrostis tremula

Production: Kg/ha air dry weight - north 800
south 1200

.43 ERGS: With Associated Depressions

Position: The dunes of this landform are in places flattened because of forces of erosion. In general, they lie in a northeast and southwest trending direction.

Macro-relief: Undulating.

Soils: Oxic quartzipsamments (Brown and reddish-brown soils of arid and semi-arid regions on loose sediments).

These sometimes lateritic soils are coarser than sandy loam and have a clay content of 15% or less. Their organic matter levels are low because of sparse vegetation. Pedologically, these soils are young because the soil forming processes have not yet resulted in the formation of genetic horizons (or have resulted in the formation of only slightly developed horizons). The parent materials may be aeolian sand deposits that border desert regions, and also weathered sandstone or paleo-pedological mantle material.

These well drained soils have below the A horizon, textures of loamy fine sand or coarser materials. They are not permanently saturated with water. The parent material of the concave portion of the dunes, because of its greater clay content, has a much better moisture holding capacity than the convex portion. Generally, the soils are suitable for extensive grazing.

Textural Profile:

Convex		Concave	
0-25 cm	Coarse Sand	0-30 cm	Sand
50-100 cm	Fine Sandy Loam	75-100 cm	Loam
100-150 cm	Loam	100-150 cm	Clay Loam

Vegetation: This landform is divided into two zones:

1. Northern zone - Convex portion of dune supports a tall shrub savanna (332).

a. Shrubs

Combretum ghasalense
Sterculia setigera
Sclerocarya birrea

b. Grasses

Aristida stipoides
Cenchrus biflorus
Eragrostis tremula

Concave portion of dune supports a non-thorny macrophyllous shrub (326).

a. Shrubs

Combretum ghasalense
Sclerocarya birrea

b. Grasses

Schoenefeldia gracilis

2. Southern zone - supports the following vegetation associations: tall shrub savanna (332), mixed tree shrub savanna (333), and dry season deciduous woodland.

a. Trees

Bombax costatum
Sclerocarya birrea

b. Shrubs

Cassia mimosoides
Combretum ghasalense
Entada africana
Sterculia setiqera
Terminalia avicennoides

c. Grasses

Andropogon gayanus
Coclospermum tinctorum
Diheteropogon hagerupii
Elyonorus elegans
Eragrostis tremula

Production: Kg/ha air dry weight
Northern zone:
convex portion of dune - 1300 Kg/ha
concave portion of dune - 1200 Kg/ha
Southern zone - 1900 Kg/ha

Table 2.2
Area Tabulations of Land Cover/Land Use Units In Dilly Study Area, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

	SANPAKA	BOFONDE	DINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL*
1 BARREN										
160 - Bare Ground			5.2			20.0		7.8		33
3 NATURAL VEGETATION										
31 GRASSLANDS										
311 Annual Grasslands	88.7	302.6	124.5	313.0	237.4	124.0	255.1	75.2	84.4	1,605
316 Graminaceous/Cyperaceous							18.0	2.0	0.2	20
32 SHRUBS										
321 Microphyllous Thorn Shrubs	82.9			57.4	10.8		129.1	50.2		330
323 Mixed Micro/Macrophyllous Shrubs							7.8	15.4		23
326 Non-Thorny Macrophyllous Shrubs	282.5	17.9		193.1	94.1	86.2	194.6	130.0	71.9	1,070
33 SAVANNAS										
331 Tree Savannas	4.5		26.5		10.7	96.1	15.5	6.2	44.9	204
332 Tall Shrub Savannas	485.7	257.8	619.4	600.3	650.4	623.4	674.9	689.2	985.9	5,594
333 Mixed Tree/Shrub Savannas	48.2	423.2	126.0	84.2	50.0	269.0	48.1	146.2	11.6	1,206
34 WOODLANDS										
342 Dry Season Deciduous		98.3	300.0	11.9	211.1	223.6	27.8	82.5	369.8	1,325
343 Mixed Evergreen/Deciduous Woodlands	4.5	20.1	34.7		9.9	34.8	25.0	22.9	2.6	154
5 AGRICULTURE										
510 Field Crops	89.0	38.8	20.9	88.9	85.5	22.4	40.8	107.3	0.8	494
560 Fallow/Abandoned Cropland	191.9	89.8	49.3	196.8	183.8	45.5	85.2	228.7	2.3	1,076
6 SETTLEMENTS										
620 Villages (no area measurement)										
Total*	1,278	1,248	1,307	1,546	1,544	1,545	1,529	1,563	1,574	13,134

*Totals are rounded

Table 2.3
Area Tabulation of Landform Units in Dilly Study Area, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

	LANDFORM	SANPAKA	BOFONDE	DINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL*
1	DEPRESSIONS										
	11 Basins w/Interior Drainage	1.0	6.2	31.3	35.3	4.4	1.0	92.1	28.6	5.8	206
	12 Small Depression Zones										
2	BOTTOMLANDS (Riparian)										
	21 Stringer or Narrow Stream Bottom	9.0	24.0	41.4		72.6	157.4	11.3	92.5	58.9	467
	22 Wide River Bottoms...										
3											
	31 Plains	75.2	60.1	171.5	58.7	66.4	98.3	49.9	78.3	69.4	728
	32 Plateaus and Benches	1.7		15.9	48.3	2.6	3.0	15.9	1.3	5.1	94
	33 Pediments (Inselbergs)	11.8	25.0	303.9	1.3		286.7	0.8		236.7	866
4	AEOLIAN SYSTEMS										
	41 Sandsheets and Plains				119.3	110.1		163.5	286.9	4.8	685
	42 Sand Complexes	600.2	864.4	266.9	491.8	331.2	668.2	561.8	525.6	680.2	4,990
	43 ERGS	579.0	268.8	475.6	790.9	956.4	330.4	633.4	549.9	513.5	5,098
Total*		1,278	1,248	1,307	1,546	1,544	1,545	1,529	1,563	1,574	13,134

*Totals are rounded

Table 2.4A
Areas of Vegetation and Land Use on Depressional Landforms for Dilly Region, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

1 Depressions = includes
11 - Basins with Interior Drainage
12 - Basins - Small Depression Zones

		SANPAKA	BOFONDE	DINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL
1	BARREN										
	160 - Bare ground			5.2							5.2
3	NATURAL VEGETATION										
	31 GRASSLANDS										
	311 Annual Grasslands							1.5			1.5
	316 Graminaceous/Cyperaceous							18.0	2.0	0.2	20.2
	32 SHRUBS										
	321 Microphyllous Thorn Shrubs							19.5	8.8		28.3
	323 Mixed Micro/Macropnyllous Shrubs							0.3			0.3
	326 Non-Thorny Macrophyllous Shrubs							0.9			0.9
	33 SAVANNAS										
	331 Tree Savannas										
	332 Tall Shrub Savannas			15.7				12.1	1.8	2.4	32.0
	333 Mixed Tree/Shrub Savannas										
	34 WOODLANDS										
	342 Dry Season Deciduous									1.0	1.0
	343 Mixed Evergreen/Deciduous Woodlands			9.4				25.0	2.5	1.6	38.5
5	AGRICULTURE										
	510 Field Crops	0.3	1.8	0.3	13.7	1.2	0.3	4.5	5.8	0.2	28.1
	560 Fallow/Abandoned Cropland	0.7	4.4	0.7	21.6	3.2	0.7	10.3	7.7	0.4	49.7

Table 2:4B

Areas of Vegetation and Land Use on Bottomland Landforms for Dilly Region, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

2 Bottomlands (Riparian), includes: 21 - Stringer or Narrow Stream Bottoms 22 - Wide River Bottoms w/ Floodplains & Terraces	SANPAKA	BOFONDE	DINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL
1 BARREN										
160 - Bare ground						17.2		7.8		25.0
3 NATURAL VEGETATION										
31 GRASSLANDS										
311 Annual Grasslands					3.0	18.4		4.1		25.5
316 Graminaceous/Cyperaceous										
32 SHRUBS										
321 Microphyllous Thorn Shrubs										
323 Mixed Micro/Macrophyllous Shrubs							3.4			3.4
326 Non-Thorny Macrophyllous Shrubs						0.4	7.9			B.3
33 SAVANNAS										
331 Tree Savannas	4.5		11.5			6.8		6.2		29.0
332 Tall Shrub Savannas		0.2	3.1		21.1	43.0		26.3	36.5	130.2
333 Mixed Tree/Shrub Savannas		5.0				20.1				25.1
34 WOODLANDS										
342 Dry Season Deciduous		0.1				8.0			22.4	30.5
343 Mixed Evergreen/Deciduous Woodlands	4.5	15.3	25.3		9.9	29.4		20.4		104.8
5 AGRICULTURE										
510 Field Crops		1.0	0.4		11.6	4.6		8.3		25.9
560 Fallow/Abandoned Cropland		2.4	1.1		27.0	9.5		19.4		59.4

Table 2.4C
Areas of Vegetation and Land Use on Plains Landforms for Dilly Region, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

31 PLAINS	SANPAKA	BOFONDE	DINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL
1 BARREN										
160 - Bare ground										
3 NATURAL VEGETATION										
31 GRASSLANDS										
311 Annual Grasslands	0.4		13.0	8.1	16.4		4.6	2.3	2.1	46.9
316 Graminaceous/Cyperaceous										
32 SHRUBS										
321 Microphyllous Thorn Shrubs	37.0			16.5						53.5
323 Mixed Micro/Macrophyllous Shrubs										
326 Non-Thorny Macrophyllous Shrubs				3.9		5.9	0.7	9.3		19.8
33 SAVANNAS										
331 Tree Savannas										
332 Tall Shrub Savannas	13.3	24.5	102.9	4.8	23.2	39.9	32.9	52.2	46.9	340.6
333 Mixed Tree/Shrub Savannas					21.4	42.2	3.0		1.8	68.4
34 WOODLANDS										
342 Dry Season Deciduous		10.4	37.7		2.8	8.0			17.3	76.2
343 Mixed Evergreen/Deciduous Woodlands										
5 AGRICULTURE										
510 Field Crops	7.5	7.5	5.4	8.3	0.8	0.8	2.6	4.4	0.3	37.6
560 Fallow/Abandoned Cropland	17.0	17.7	12.5	17.1	1.8	1.5	6.1	10.1	1.0	84.8

Table 2.4D

Areas of Vegetation and Land Use on Plateaus and Benches Landforms for Dilly Region, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

32 PLATEAUS & BENCHES	SANPAKA	BOFONDE	DINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL
1 BARREN										
160 - Bare ground										
3 NATURAL VEGETATION										
31 GRASSLANDS										
311 Annual Grasslands							4.1			4.1
316 Graminaceous/Cyperaceous										
32 SHRUBS										
321 Microphyllous Thorn Shrubs				2.0						2.0
323 Mixed Micro/Macrophyllous Shrubs										
326 Non-Thorny Macrophyllous Shrubs	1.2			25.1			2.7	1.3		30.3
33 SAVANNAS										
331 Tree Savannas									3.7	3.7
332 Tall Shrub Savannas	0.5		11.0	9.9		2.1	6.8			30.3
333 Mixed Tree/Shrub Savannas										
34 WOODLANDS										
342 Dry Season Deciduous			3.8	6.7		0.9	2.3		1.4	15.1
343 Mixed Evergreen/Deciduous Woodlands										
5 AGRICULTURE										
510 Field Crops			0.3	1.4	0.8					2.5
56D Fallow/Abandoned Cropland			0.8	3.2	1.8					5.8

Table 2.4E
Areas of Vegetation and Land Use on Pediments Landforms (including Inselbergs) for Dilly Region, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

33 PEDIMENTS, including inselbergs	SANPAKA	BOFONDE	DINYAN.	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL
1 BARREN										
160 - Bare ground										
3 NATURAL VEGETATION										
31 GRASSLANDS										
311 Annual Grasslands						5.4				5.4
316 Graminaceous/Cyperaceous										
32 SHRUBS										
321 Microphyllous Thorn Shrubs										
323 Mixed Micro/Macrophyllous Shrubs										
326 Non-Thorny Macrophyllous Shrubs						25.2	0.5		55.0	80.7
33 SAVANNAS										
331 Tree Savannas										
332 Tall Shrub Savannas	5.3	17.5	115.6			133.9	0.3		123.7	396.3
333 Mixed Tree/Shrub Savannas			47.3			11.6			1.3	60.2
34 WOODLANDS										
342 Dry Season Deciduous		7.5	1283			80.9			55.6	272.3
343 Mixed Evergreen/Deciduous Woodlands						3.0			1.0	4.0
5 AGRICULTURE										
510 Field Crops	1.9		3.8	0.3		8.7				14.7
560 Fallow/Abandoned Cropland	4.6		8.9	1.0		18.0			0.1	32.6

Table 2.4F

Areas of Vegetation and Land Use on Aeolian Sandsheets and Plains Landforms for Dilly Region, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

4 AEOLIAN SYSTEMS 41 SANOSHEETS & PLAINS	SANPAKA	BOFONDE	OINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL
1 BARREN										
160 - Bare ground										
3 NATURAL VEGETATION										
31 GRASSLANDS										
311 Annual Grasslands				8.1	0.5		20.0	9.6		38.2
316 Graminaceous/Cyperaceous										
32 SHRUBS										
321 Microphyllous Thorn Shrubs					10.8		91.3	40.3		142.4
323 Mixed Micro/Macrophyllous Shrubs										
326 Non-Thorny Macrophyllous Shrubs				25.4	6.0		4.3	8.4	3.4	47.5
33 SAVANNAS										
331 Tree Savannas										
332 Tall Shrub Savannas				25.1	14.8		14.4	69.8	1.4	125.5
333 Mixed Tree/Shrub Savannas				14.3						14.3
34 WOODLANDS										
342 Dry Season Deciduous				5.2			15.7	7.3		28.2
343 Mixed Evergreen/Deciduous Woodlands										
5 AGRICULTURE										
510 Field Crops				12.1	26.4		5.3	45.5		89.3
560 Fallow/Abandoned Cropland				29.1	51.6		12.5	106.0		199.2

Table 2.4G

Areas of Vegetation and Land Use on Aeolian Sand Complex Landforms for Dilly Region, Summarized by Photo Base Map Sheet, Areas Given In Square Kilometers

42 SAND COMPLEXES	SANPAKA	BOFONDE	DINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL
1 BARREN										
160 - Bare ground						1.8				1.8
3 NATURAL VEGETATION										
31 GRASSLANDS										
311 Annual Grasslands	84.8	252.8	26.0	116.9	50.7	62.6	65.7	20.9	53.0	733.4
316 Graminaceous/Cyperaceous										
32 SHRUBS										
321 Microphyllous Thorn Shrubs	14.9						9.0	1.1		25.0
323 Mixed Micro/Macrophyllous Shrubs							4.1	15.4		19.5
326 Non-Thorny Macrophyllous Shrubs	41.5	17.9		33.4	40.7	52.8	86.5	20.2	3.7	296.7
33 SAVANNAS										
331 Tree Savannas			15.0		10.7	88.7	15.5		40.6	170.5
332 Tall Shrub Savannas	192.5	94.5	123.0	217.0	150.9	262.3	273.8	149.8	422.6	1,886.4
333 Mixed Tree/Shrub Savannas	48.2	397.0	50.7	66.1	17.4	130.6	44.8	146.2	8.5	909.5
34 WOODLANDS										
342 Dry Season Deciduous		13.1	33.4		37.3	54.8	9.8	75.2	151.8	375.4
343 Mixed Evergreen/Deciduous Woodlands						2.4				2.4
5 AGRICULTURE										
510 Field Crops	70.1	27.1	5.6	17.3	7.1	4.2	17.2	33.0		181.6
560 Fallow/Abandoned Cropland	148.2	62.0	13.2	41.1	16.4	8.0	35.4	63.8		388.1

Table 2.4H
Areas of Vegetation and Land Use on Aeolian ERG Landforms for Dilly Region, Summarized by Photo Base Map Sheet.
Areas Given In Square Kilometers

43 ERGS	SANPAKA	BOFONDE	DINYAN	FARKELI	DALI	FALOU	KORONGA	DILLY	MOURDIAH	TOTAL
1 BARREN										
160 - Bare ground						1.0				1.0
3 NATURAL VEGETATION										
31 GRASSLANDS										
311 Annual Grasslands	3.5	49.8	85.5	179.9	166.8	37.6	159.2	38.3	29.3	749.9
316 Graminaceous/Cyperaceous										
32 SHRUBS										
321 Microphyllous Thorn Shrubs	31.0			38.9			9.3			79.2
323 Mixed Micro/Macrophyllous Shrubs										
326 Non-Thorny Macrophyllous Shrubs	239.8			105.3	47.4	1.9	91.1	90.3	9.8	585.6
33 SAVANNAS										
331 Tree Savannas						0.6			0.6	1.2
332 Tall Shrub Savannas	274.1	121.1	248.1	343.5	440.4	142.2	341.4	389.3	352.4	2,652.5
333 Mixed Tree/Shrub Savannas		21.2	28.0	3.8	11.2	64.5	0.3			129.0
34 WOODLANDS										
342 Dry Season Deciduous		67.2	96.8		171.0	71.0			120.3	526.3
343 Mixed Evergreen/Deciduous Woodlands		4.8								4.8
5 AGRICULTURE										
510 Field Crops	9.2	1.4	5.1	35.8	37.6	3.8	11.2	10.3	0.3	114.7
560 Fallow/Abandoned Cropland	21.4	3.3	12.1	83.7	82.0	7.8	20.9	21.7	0.8	253.7

MATRICE DES UNITES ECOLOGIQUES
ECOLOGIC UNITS MATRIX

LA MATRICE DES UNITES ECOLOGIQUES IDENTIFIE PAR SECTION NUMEROTEE DE LA CARTE LES COMBINAISONS D'ASSOCIATIONS DE VEGETATION ET DES CONFIGURATIONS DU TERRAIN QUI SE TROUVENT DANS LA REGION DE DILLY TOUCHEE LE PROJET

THE ECOLOGIC UNITS MATRIX IDENTIFIES, BY MAP SECTION, THOSE COMBINATIONS OF VEGETATION ASSOCIATION AND LANDFORM WHICH OCCUR IN THE DILLY PROJECT AREA

				1 DEPRESSIONS (NON-RIVERAINES)		2 ZONES BASSES (RIVERAINES)		3 SURFACES PLANES			4 SURFACES EOLIENNES					
				11 BASSINS SANS DRAINAGE EXTERIEUR, GENERALEMENT AVEC PLAYAS OULACS	12 BASSINS PETITES ZONES DE DEPRESSION	21 PETITE RAVIN OU FONDS FLUVIAUX ETROITS	22 FONDS FLUVIAUX LARGES AVEC PLAINES ALLUVIALES ET TERRACES	31 PLAINES	32 PLATEAUX, MESAS ET BUTTES	33 PEDIMENTS, Y COMPRIS DES "INSELBERGS"	41 COUCHES SABLONNEUSES ET PLAINES	42 DUNES DE FORMES IRREGULIERES	43 ERGS (DUNES LONGITUDINALES, AVEC DEPRESSIONS)			
1 BARREN		BARE GROUND (SLICK AREAS) 160		6	6	6,8	6,8					8	8	TERRE NUE COMPOSEE DE VASE/ARGILE 160		1 STERILE
3 NATURAL VEGETATION	31 GRASS LANDS	ANNUAL GRASSLANDS 311		3	3	5,6,8	5,6,8	1,2,3,5, 6,7,9	3	8	2,3,5,6	0	0	PRAIRIE ANNUELLE 311	31 PRAIRIE	3 VEGETATION NATURELLE
		GRAMINACEOUS/CYPERACEOUS GRASSES 316		3,6,9	3,6,9									GRAMINACEAE/CYPERACEES 316		
	32 SHRUBS	MICROPHYLLUS THORN SHRUBS 321		3,6	3,6			1,2	2		3,5,6	1,3,6	1,2,3	BROUSSAILLE EPINEUSE A MICROPHYLLUS 321	32 VEGETATION ARBUSTIVE	
		MIXED MICROPHYLLUS/ MACROPHYLLUS SHRUBS 323		3	3	3	3					3,6		ARBUSTIVE MIXTE A MICROPHYLLUS/MACROPHYLLUS 323		
		NON-THORNY MACROPHYLLUS SHRUBS 326		3	3	3,8	3,8	2,3,6,8	1,2,3,6	3,8,9	2,3,5, 6,9	1,2,3,4, 5,6,8,9	1,2,3,5, 6,8,9	ARBUSTIVE NON EPINUSE A MACROPHYLLUS 326		
	33 SAVANNAS	TREE SAVANNAS 331				1,6,7,8	1,6,7,8		9			3,5,7, 8,9	8,9	SAVANE ARBORESCENTE 331	33 SAVANE	
		TALL SHRUB SAVANNAS 332		3,6,7,9	3,6,7,9	4,5,6, 7,8,9	4,5,6, 7,8,9	0	1,2,3, 7,8	1,3,4 7,8,9	2,3,5, 6,9	0	0	SAVANE A GRANDS ARBUSTES 332		
		MIXED TREE/SHRUB SAVANNAS 333				4,8	4,8	3,5,8,9		7,8,9	2	0	2,3,4, 5,7,8	SAVANE MIXTE ARBORESCENTE/ARBUSTIVE 333		
	34 WOODLANDS	DRY SEASON DECIDUOUS WOODLANDS 342		9	9	4,8,9	4,8,9	4,5, 7,8,9	2,3, 7,9,9	4,7,8,9	2,3,6	3,4,5, 6,7,8,9	4,5, 7,8,9	TERRE BOISEE A FEUILLAGE CADUC EN SAISON SECHE 342	34 TERRE BOISEE	
		MIXED EVERGREEN/ DECIDUOUS WOODLANDS 343		3,6,7,9	3,6,7,9	1,4,5, 6,7,8	1,4,5, 6,7,8			8,9		8	4	TERRE BOISEE MIXTE FEUILLAGE CADUC/SEMPER VIRENS 343		
5 AGRICULTURE		FIELD CROPS 510		0	0	4,5, 6,7,8	4,5, 6,7,8	0	2,5,7	1,2, 7,8,9	2,3,5,6	1,2,3,4, 5,6,7,8	0	CHAMPS CULTIVES 510	5 AGRICULTURE	
		FALLOW/ABANDONED CROPLAND 560		0	0	4,5, 6,7,8	4,5, 6,7,8	0	2,5,7	1,2, 7,8,9	2,3,5,6	1,2,3,4, 5,6,7,8	0	ZONE DE CULTURE EN FRICHE/ASANDONNEE 560		

ASSOCIATION DE VEGETATION / CONFIGURATION DU TERRAIN

VEGETATION ASSOCIATION / LANDFORM

				11 BASINS WITH INTERNAL DRAINAGE, USUALLY WITH PLAYAS OR LAKES	12 BASINS SMALL DEPRESSION ZONES	21 STRINGER OR NARROW STREAM BOTTOMS	22 WIDE RIVER BOTTOMS WITH FLOODPLAINS AND TERRACES	31 PLAINS	32 PLATEAUS, MESAS AND BUTTES	33 PEDIMENTS, INCLUDING INSELBERGS	41 SANDSHEETS AND PLAINS	42 SAND COMPLEXES	43 ERGS (LONGITUDINAL DUNES WITH DEPRESSIONS)
				1 DEPRESSIONS (NON RIPARIAN)		2 BOTTOMLANDS (RIPARIAN)		3 PLANAR SURFACES			4 AEOLIAN FEATURED LANDSCAPES		

INDEX AUX SECTIONS DE LA CARTE

INDEX TO MAP SECTIONS

1= SANPAKA	6= DILLY
2= FARKELI	7= DINYAN
3= KARONGA	8= FALOU
4= BOFONDE	9= NOURDIAH
5= DALI	0= TOUTES LES SECTIONS

2.6 SUMMARY

The objectives of the Dilly project have been accomplished. The results of the study, in the form of mapping products, findings and observations, can now be integrated into a Range Management Plan which could resolve or ameliorate some of the problems observed during the conduct of the study.

Of the several problems associated with increasing livestock production in the Dilly project area, none is as limiting or severe as that of providing adequate feed on a year-long basis. The situation is, in fact, one of feast or famine where, during the rainy season (July, August, September and October), the annual grasses produce an abundance of green feed. As the annual grasses die back in October and November, they become almost worthless as forage. From November to July, very little native feed, other than perennial grasses, is available. Resident livestock herds of the villagers suffer because of low production of perennials and under utilization of crop residues near villages.

There are several approaches to a solution of these problems, none of which is adequate in itself, but by applying combinations of standard range management practices, it is possible to provide some degree of improvement over existing conditions.

1. Increased production of browse plants is an important component of native vegetation. Browse or woody plants are a natural part of the Sahel vegetation zone. Such plants retain a higher protein content during the dry season than do grasses. Livestock, including cattle, rely on such feed under dry conditions. Browse plants such as Acacia spp. and Combretum spp. are relatively suppressed in the Dilly Study Area. This is due in part to the recent drought which killed many of the woody plants. In the main, however, this suppression is due to the annual indiscriminate burning common in the area. Fire is especially damaging to the young seedling plants. One of the greatest problems concerning feed is that the seedling age class generally is absent in the Dilly Study Area. In order to have healthy browse production; all age classes must be present. Throughout the study area, fire is a significant suppressant of woody vegetation.

2. Present utilization of crop land abandoned from cropping is nil. Many thousand hectares of land lie idle when cultivated crops are rotated to new land. After several years, a poor stand of annual vegetation occupies these abandoned areas. Production of perennial grasses and legumes on such lands could contribute greatly to a broader feed base, because perennials furnish adequate feed for a longer period of time than do annuals. The desirable forage period of perennials extends for two months after annuals have died back. In addition, the presence of legumes would add to the natural fertility of the land through the nitrogen they return to the soil.

3. An efficient method of preserving feed for the dry season does not exist. During the rainy season, an abundance of good native feed is produced far beyond the current livestock needs. Such feed, while green and nutritious, is not stored as hay or silage, and therefore a good feed source is lost.

4. Crop residues are seriously under untilized. It is a common practice in the Dilly Study Area to leave millet or sorghum stems and stocks on the fields after harvest. Normally, they are piled and burned in preparation of the fields for a new crop. These crop residues, lacking proper attention for storage and preservation, are lost as feed to livestock during the dry season.

5. Discussions with OMBEVI and FAO specialists disclosed a general need for reseeding programs. EarthSat's range specialists discussed the need for a management plan to accomodate the increased forage production which would result from reseeding operations. It also was noted that, based upon U.S. experience in arid land seeding operations, an adequate seed source is normally difficult to provide and often becomes a severe limiting factor. Information contained in EarthSat's photomap products can provide valuable assistance to Dilly seeding operations.

6. A problem inherent to the study area is the provision of adequate stock water. The development of water, by itself, without careful planning for the grazing management of the area involved, can lead to destructive land use. However, water developments placed in the right places can be an aid in distributing livestock over the range and could obtain a more even utilization of the forage crop over a wider area.

   Proper use of the Skylab Ground Water Exploration Guide Maps can greatly facilitate the search for propitiously located range water sources. In addition, these Guide Maps, in similar areas, have significantly reduced the cost of hydrologic surveys.

7. Uncontrolled burning is one of the greatest problems in the Dilly Study Area. As mentioned earlier, it is very damaging to browse a regenerating range when it occurs while plants are in the seedling stage. The effect of repeated fire on the soil needs further study. It is probable that fire is one of the factors which has eliminated perennial grasses over much of the Dilly Study Area. Conversely, <u>controlled</u> burning is one of the most effective and economical tools of range management, but it can be effective and safe only when integrated into an operable Range Management Plan. The Dilly range is considered by EarthSat specialists experts to be particularly amenable to a well designed burning program.

It is recognized that any changes in current range practices will significantly impact both the biological and the cultural sructure of the region. The study findings and products can provide considerable guidance in developing programs which will reduce negative impacts and increase positive impacts of project interventions.

Various types of development are illustrated and described in the "Structural Range Improvement Handbook," prepared by the U.S. Forest Service and distributed to the participants of the training session held in Bamako in October, 1976. These handbooks are a practical and powerful aid in range development.

EarthSat believes that the accompanying graphic products, with their interpretive legends, developed during this project are the single most valuable tool available for further planning in the Dilly Study Area. When properly integrated into a Range Management Plan, they provide an adequate base for continued development.

3. NEWLANDS: A RECONNAISSANCE LEVEL STUDY OF RANGE RESOURCES AND TSETSE HABITATS

3.1 INTRODUCTION

The Newlands program is designed to assist the government and people of Mali in the expansion of livestock production in regions of important rangeland. The subsequent Mali II programs, which go far beyond the scope of the present study, involve as a first objective, the control of tsetse fly (Glossina spp). The objective of the second phase of the Mali II program is to demonstrate benefits and proper phasing, or sequencing, of developmental activity in opening newly available lands for improved livestock and agricultural utilization.

In support of the Newlands program, EarthSat conducted reconnaissance level examinations and analyses of the three candidate Newlands study areas - Kita, Dioila, and Monts Mandingues. This work was designed specifically to provide information helpful in selection of a tsetse control test area from among the three candidate locations. As such, it was conducted at 1:200,000 scale - a smaller scale than the Dilly Range Site Survey, and in keeping with the intent of the reconnaissance level study required by OMBEVI and USAID. In addition to field observations, digitally processed LANDSAT images were prepared to serve as image basemaps and to provide substantial information through image analysis.

EarthSat's study of the Newlands locations focuses on two basic objectives. The first is to provide a reconnaissance level survey of tsetse habitats based on LANDSAT analysis, supported by brief field observations. Section 3.4 is a discussion and map prepared by Dr. K.J.R. MacClennan on "Tsetse Habitat Distribution and Reclamation Prospects."

The second objective is to provide a reconnaissance level survey of rangeland resources and other general considerations concerning land use potential in the candidate areas. This discussion, prepared by Mr. W.F. Currier and other members of EarthSat's staff, addresses a variety of factors relating to range resources and operation of a livestock program in the Newlands program areas, it is presented in Section 3.2. In discussing the geographic entities of each location (i.e., Kita, Dioila, and Monts Mandingues), reference is made to "Land Units" which are mapped as a means of ecologically partitioning the Newlands study areas into areas of relatively homogeneous resources and management requirements. These Land Units are described in Section 3.3 and were derived through combined field observations and LANDSAT analyses. Maps showing their location and distribution were prepared at 1:200,000 scale on overlays to LANDSAT image basemaps.

Preparation of Map Products

The cartographic products prepared during this contract for the Newlands study areas consist of:

a) Digitally Enhanced LANDSAT Image Basemap
b) Overlays showing Land Units
c) Overlays showing Drainage and Forest Reserves

The LANDSAT Image Basemaps were prepared for analysis and for use as a cartographic base, to which corresponding overlays are registered.

The Use of LANDSAT

Land resource information, previously incomplete or non-existent, may be provided in Mali using remotely sensed data, particularly LANDSAT imagery, with supplemental aerial photography and field surveys. One value of remote sensing is that it captures and preserves all observable resource details (to the resolution limits of the system) exactly as it is at an instant in time. These records can be preserved for re-examination and analysis in greater depth as future developments or programs require. This procedure has been followed since the serious use of aerial photography in agriculture and natural resources began in the late 1930's to early 1940's.

LANDSAT-1 and 2, launched in July 1972 and January 1975 respectively, have added four new dimensions to the traditional values of aerial photography:

1. A large synoptic view provided by each full frame, which is 185 kilometers square and covers 34,225 square kilometers.

2. The capability at very low cost to look at the same area repeatedly at the same sun time. Each satellite orbit is configured to pass over each point on the earth's surface every 18 days at approximately 0930 hours local sun time.

3. The resolution and scale inherent in the system compress data and the results are more appropriate for a generalized regional view of the resource base, i.e., a reconnaissance level analysis. LANDSAT resolution is approximately 80 meters depending upon the instantaneous field-of-view (IFOV) of the multispectral scanner (MSS). Geometric and geodetic accuracy of MSS imagery is approximately 200 meters uncorrected and 80 meters corrected (the latter figure exceeds the horizontal positional accuracies of 1:200,000 scale topographic maps).

4. LANDSAT imagery is available at nominal cost after it has been acquired by the satellite. For example, a 1:200,000 scale color composite print, computer enhanced and processed costs less than U.S. $1,250 (over 28 square kilometers for one U.S. dollar).

Although 1:50,000 scale black-and-white aerial photography is available for portions of Mali, recent coverage is very incomplete, and for regional reconnaissance mapping does not represent a better option

than LANDSAT images. For semi-detailed and detailed studies, however, such as the Dilly Range Site Surveys, aerial photography is the appropriate data source. For any given LANDSAT scene, hundreds of aerial photographs would be required (approximately 300 frames of 1:50,000 scale equal one LANDSAT scene). Interpretation of these data, using conventional techniques on a regional scale, would be time consuming and expensive.

When working with LANDSAT imagery, particularly at 1:200,000 scale, topographic maps are valuable sources of corollary information. These data are readily integrated into all resource interpretations and analyses and are particularly helpful in evaluating macro-relief and landform characteristics. Topographic maps also help in identifying and examining infrastructure of the landscape.

Aerial photography, including low altitude oblique photographs as well as black-and-white aerial mapping photography, are also important corollary information. In the Newlands study areas, black-and-white photos were unavailable. Therefore, color oblique photos were acquired during field surveys using hand-held Hasselblad 70mm and 35mm cameras. These data provide large scale insight into the vegetation, surficial hydrology and topographic conditions represented by color density and pattern characteristics of the multispectral LANDSAT imagery. When used on a sampling basis, as in the present study, they lead to higher accuracies and confidence levels for LANDSAT interpretations and resource analysis. These photographs are also used to illustrate particular features in this report.

Digitally Enhanced LANDSAT Images

A wide variety of LANDSAT images is presently available for most areas of Mali. EarthSat has conducted a selective search and identified most recent and relatively cloud free images for the entire national territory. This information is presented in Appendix C. From this listing, four scenes were selected which cover the Newlands study areas as follows:

2400-10022	26 February 1976
2383-10083	9 February 1976
2402-10132	28 February 1976
2402-10135	28 February 1976

In the use of LANDSAT imagery, information requirements of the natural resource scientist vary. To meet varying user needs, EarthSat has developed a set of computer processing procedures for improving or maximizing qualities of a LANDSAT scene that are of greatest interest. In the present study, LANDSAT scenes for the mid-dry season (February) were selected as the optimal choice of those available images for the study objectives. These LANDSAT images were subjected to the following computer processing:

- Digital image edge enhancement increases the contrast of color intensity along boundaries within the image. This process improves interpreters' ability to rapidly identify linear and

border features such as agricultural field boundaries, land use interfaces, geologic faults, marked relief or structure changes, surface water limits, and lithology changes.

- Geometric rectification repositions digitally processed images to simulate a projection closely representative of the earth's surface in the immediate region. The resultant digital image product is suitable for super-imposition on maps and possesses improved scale accuracies. (It is noted that the 1:200,000 scale Newlands LANDSAT images do not always correspond to existing 1:200,000 topographic maps, particularly in regard to the location and position of some rivers. After a thorough analysis, EarthSat has concluded that the LANDSAT images are substantially correct in the geometric positioning of imaged features.)

- Gray scale adjustment is a contrast enhancement algorithm which manipulates the range of gray values to produce a final photographic product that visually highlights selected features of an image.

Following computer processing, the LANDSAT images were photographically processed to produce false color images. In this type of image, high infrared reflectance features are rendered red; as a result, healthy green vegetation will appear red, as noted along drainages where gallery forests occur. The four images were then mosaicked in order to prepare the LANDSAT Image Basemaps. Although the LANDSAT Image Basemaps cover less than the area of a single full LANDSAT scene, their relative locations required mosaicking of two images for Dioila and three images for Kita study areas.

Following preparation of the LANDSAT Image Basemaps, two overlays were prepared for each study area; Drainages and Forest Reserves Overlays, and Land Units Overlays, as described below.

Drainages and Forest Reserves Overlays

The location and character of stream and river courses is an important consideration in the analysis of tsetse habitats as discussed in Section 3.4. Therefore, principal stream and river channels were delineated on an overlay to the LANDSAT Image Basemaps. Existing topographic maps were carefully consulted during this analysis; the principal data source, however, was the LANDSAT image. The correct location of the drainage network is considered to be most accurate on the LANDSAT images.

When comparing both the LANDSAT image and the appropriate topographic maps it may be noted that not all minor streams have been delineated. Streams shown on the overlay are generally characterized on a LANDSAT image by a narrow red line indicative of riparian tree cover, or a gallery forest. These are potential habitats for Glossina palpalis and G. tachinoides. Those drainages which do not have the riparian vegetation

indicators, or are not otherwise readily apparent on the LANDSAT image, are less likely to be tsetse habitats and are not delineated on the drainage overlay.

Also shown on the same overlay are Forest Reserves, the locations of which were transferred directly from corollary topographic maps. Because of current land management policies and practices with respect to many of these reserves, they often provide protected primary dry season habitats for both Glossina morsitans and G. palpalis as discussed in Section 3.4. The distribution and areal relationships of forest reserves is, therefore, important to the general consideration of tsetse habitats, and this information is included on the overlays.

Land Units Overlays

Land Units were derived through analyses of digitally enhanced LANDSAT false color images, existing topographic maps, and aerial and ground observations. Overlay maps showing Land Unit location and distributions were prepared at 1:200,000 scale and registered to each corresponding LANDSAT Image Basemap.

Regional landform differences are the basis upon which the Land Unit categories were initially identified and delineated. Also included in this analysis, however, were such ecologic and environmental features as vegetation, soils, and extent of cultivation (land use). The Land Unit categories were named after the predominant landform feature within each Land Unit, consisting of:

1) Dissected Plateaus with Broad Valleys, (PAL)
2) Dissected Plateaus with Narrow Valleys (PAe)
3) Plains (P)
4) Undulating Plains (PO)
5) Rolling Hills (CO)
6) Terraces (TER)
7) Wide Floodplains (PLi)

The approximate area of each Land Unit type, by study area, is shown on Table 3.1. In the following section, for each Land Unit type, by study area, the following characteristics are discussed: location and geomorphic characteristics, vegetation and soils, land use.

TABLE 3.1

Summary of Land Unit Areas In Hectares

Land Unit	Kita	Dioila	Monts Mandingues	Total
Dissected Plateau (Broad Valley)	418,800	173,500	69,300	661,600
Dissected Plateau	139,600		124,000	263,600
Plain	558,400	130,000		688,400
Undulating Plain		65,000	69,300	134,300
Rolling Hills	139,600			139,600
Terrace	69,800	21,700	69,300	169,800
Wide Flood Plain	69,800	43,400	17,500	130,700
Total	1,396,000	433,600	349,400	2,179,000

3.2 ANALYSIS OF RANGE RESOURCES POTENTIAL

The range potential analysis of the Newlands Study Areas - Kita, Monts Mandingues and Dioila - considered the following factors relating to range resources and livestock program operations: native feed base, crop aftermath availability, needed livestock of water developments, topography, and livestock operation types. Each of these factors, briefly described below, were used to evaluate and comparatively rank each study area, thereby providing a basis of selection of one area for developing livestock improvement programs.

Several tables accompany this discussion; Table 3.2 summarizes Range Resources and Livestock Program Operations Factors for each study area. Tables 3.3, 3.4 and 3.5 for Kita, Monts Mandinques, and Dioila Study Areas, respectively, contain the following additional information for each Land Unit:

- Size of each Land Unit
- Herbage Production and Grass Types
- Present Agricultural Land Use
- Native Feed Base
- Crop Aftermath Availability
- Livestock water developments
- Topography
- Types of livestock operations

Following a review and analysis of all available data and visits to each study area, comparative rating assessments were compiled by senior range management specialists. From this analysis, the EarthSat team concludes that the Kita Study Area provides the greatest potential for further developing livestock programs based on its extant natural and cultural resources. In order of potential, the Study Areas are ranked as follows:

1. Kita
2. Monts Mandingues
3. Dioila

The following factors relating to range resources and livestock program operations were considered:

- Native Feed Base

  Both the amount and kind of native feed were considered. Distinction between perennial and annual species is essential to all range improvement and management activities in the Newlands study areas (as well as in Dilly, as discussed in Chapter 2). Present range management activities are, in general, debilitating to both project areas. Of particular concern are culturally stimulated burning practices and a lack of understanding of fundamental range management principles, i.e., the greater benefits of maintaining perennial forage over annual forage. Perennial plants, generally, produce significantly more feed and a better quality of feed over a longer period of time.

In the present analysis the native feed base has been divided into three categories of production: High (over 2,500 kilograms per hectare); Medium (1,500 to 2,500 kilograms per hectare); and Low (under 1,500 kilograms per hectare). A percentage figure relating annuals to perennials is given for all Land Units in the accompanying tables (i.e., Tables 3.2, 3.3, 3.4, and 3.5). This is one of the most important factors in selecting areas planned for improvement and management activities.

- Crop Aftermath Availability

Residue of agricultural crops is an important component of additional feed which may be available to the production of livestock. This is available in the farming areas, and its extent is indicated for each Land Unit.

- Needed Livestock Water Developments

All livestock programs are critically dependent upon adequate livestock watering sites. Livestock water developments not only fulfill requirements of livestock, but if properly located will aid in proper distributions of livestock on ranges. Needed water developments are generally placed in three categories: Many, Some, Few. Since range water developments are relatively expensive, an indication is given by individual Land Units of the magnitude of needed water developments in each study area. The accompanying tables identify these development needs.

- Topography

Topography is important from the standpoint of livestock movement through an area and/or difficulty of herding cattle into a specific grazing site. Topography also is important in determining the ease of obtaining equitable utilization of a given range. Topographic conditions are divided into two categories: Steep and Flat.

- Livestock Operation Types

Two basic livestock operations of the Newlands Areas were considered: (1) Transhumant/Migratory; and (2) Local/Sedentary use. Transhumant/Migratory herding operations were then considered within three categories: good areas for Transhumant operations, poor areas for Transhumant operations, and areas where coordination of Transhumant operations with agriculture is needed. An example of a poor area for transhumant operations is one of low forage production and rough terrain (i.e., steep topography). A good area for transhumant operations is one where cattle are not hindered in their movement by terrain conditions, a dominance of perennial grasses is present, and

no conflict exists with agricultural activities. An area where coordination with agriculture is needed does not necessarily mean it is undesirable for use by transhumant livestock operations, but rather that a use (agriculture) already exists and coordination is necessary to accommodate migratory grazing activities.

Local/Sedentary livestock operations consist of agricultural settlements where small herds of livestock (cattle, goats and sheep) are maintained. Given alternative management practices, it may be possible to increase the size and production of these herds, as well as accommodate transhumant livestock operations. Sedentary livestock operations in each of the Newlands areas were considered and rated as Good, Fair, and Poor. Factors considered in these ratings included distance of available ranges from village settlements, types and amounts of forage and forage production, terrain conditions and other factors relevant to livestock movement.

PHOTOGRAPHIC ILLUSTRATIONS OF NEWLANDS FEATURES

The following illustrations depict ecological scenes which were utilized in the evaluation of range potential for the Newlands area. A larger number of photographs was acquired concurrent with aerial ground observations to aid in overall judgement for the candidate areas. These photographs represent typical situations which served as criteria in the ranking and selection process.

TABLE 3.2

SUMMARY OF RANGE LIVESTOCK POTENTIAL - NEWLAND PROJECT

	KITA		DIOILA		MONTS MANDINGUE	
	%Area	Hectares	%Area	Hectares	%Area	Hectare
Total Study Area	100	1,396,000	100	433,600	100	349,400
Potential Native Feed Base		1*		3*		2*
High: > 2,500 Kg/ha	45	628,200	45	195,100	23	80,300
Medium: 1,500-2,500 Kg/ha	40	558,400	15	65,000	40	139,800
Low: < 1,500 Kg/ha	15	209,400	40	173,500	37	129,300
Crop Aftermath Availability		3*		1*		2*
Abundant	45	628,200	45	195,100	63	220,100
Scarce	30	418,800	55	238,500	0	-
None	25	349,000	0	0	37	129,300
Stockwater Development Needs		1*		2*		3*
Many	20	279,200	15	65,000	57	199,200
Some	70	977,200	70	303,600	20	69,900
Few	10	139,600	15	65,000	23	80,300
Topography		1*		3*		2*
Steep - Hinders livestock movement	40	558,400	40	173,500	57	199,200
Flat - No hindrance to livestock movement	60	837,600	60	260,100	43	150,200
Livestock Operations						
1. Transhumance Use		1*		3*		2*
° Good - no conflicts	45	628,200	15	65,000	3	10,400
° Poor - low production area	10	139,600	40	173,500	57	199,200
° Coordination with agriculture needed	45	628,200	45	195,100	40	139,800
2. Sedentary Use		1*		3*		2*
Good	45	628,200	45	195,100	23	80,300
Fair	30	418,800	15	65,000	40	139,800
Poor	25	349,000	40	173,500	37	129,300
Total - Factor Weights		8*		15*		13*

*Selection of candidate areas best suited for range development based upon the above weighting factors.

First Candidate KITA 8

Second Candidate MONTS MANDINGUES 13

Third Candidate DIOILA 15

TABLE 3.3. CRITERIA FOR EVALUATING LIVESTOCK POTENTIAL: KITA STUDY AREA

LAND UNIT	SIZE	RANGE VEGETATION		POTENTIAL LIVESTOCK PRODUCTION FACTORS					LIVESTOCK OPERATION TYPE	
		PRODUCTION	KIND	PRESENT AGRICULTURAL LAND USE	NATIVE FEED BASE	CROP AFTERMATH AVAILABILITY	LIVESTOCK WATER DEVELOPMENTS	TOPOGRAPHY	TRANSHUMANT / MIGRATORY HERDS	LOCAL/SEDENTARY HERDS
PLAINS	558,400 HA (40%)	4,000 KG/HA	PERENNIALS 50% ANNUALS 50%	OVER 50% OF AREA CULTIVATED	HIGH	ABUNDANT	PERENNIAL STREAMS. SOME WATER MUST BE DEVELOPED TO MAKE FULL USE OF FEED	FLAT. GOOD MOVEMENT OF LIVESTOCK THROUGHOUT AREA	MUST BE COORDINATED WITH AGRICULTURAL USE	GOOD. CAN BE INCREASED
DISSECTED PLATEAUS WITH BROAD VALLEYS	418,800 HA (30%)	3,000 KG/HA	PERENNIALS 40% ANNUALS 60%	15% OF AREA CULTIVATED	MEDIUM	SOME AVAILABLE	NEEDS ADDITIONAL WATER DEVELOPMENT	BROKEN WITH SMOOTH SLOPE SYSTEM. MOVEMENT OF LIVESTOCK ONLY SLIGHTLY HINDERED	GOOD. LENDS ITSELF TO THIS TYPE OF OPERATION	MODERATE AREAS ADJACENT TO VILLAGES CAN BE USED
DISSECTED PLATEAUS WITH NARROW VALLEYS	139,600 HA (10%)	1,500 KG/HA	PERENNIALS 20% ANNUALS 80%	LESS THAN 10% OF AREA CULTIVATED	LOW	SCARCE	NEED CONSIDERABLE WATER DEVELOPMENT	BROKEN WITH ANGULAR SLOPE SYSTEM. LIVESTOCK MOVEMENT GREATLY HINDERED BY TOPOGRAPHY	POOR	SMALL AMOUNT OF USE BY LOCAL VILLAGES. HERBAGE PRODUCTION LOW. CANNOT SUPPORT MANY LIVESTOCK
ROLLING HILLS	139,600 HA (10%)	(1) WESTERN UNIT 2,500 K G/HA	PERENNIALS 25% ANNUALS 75%	LESS THAN 10% OF AREA CULTIVATED	(1) MEDIUM	SCARCE	NEED CONSIDERABLE DEVELOPMENT	ROLLING DOES NOT HINDER LIVESTOCK MOVEMENT	WESTERN UNIT GOOD	POOR
		(2) EASTERN UNIT 3,500 KG/HA	PERENNIALS 45% ANNUALS 55%	OVER 50% OF AREA CULTIVATED	(2) HIGH	ABUNDANT	SOME WATER DEVELOPMENT NEEDED TO SUPPLEMENT EXISTING WATER		EASTERN UNIT MUST BE COORDINATED WITH AGRICULTURAL USE	GOOD. CAN BE INCREASED
TERRACES	69,800 HA (5%)	1,500 KG/HA KG/HA	PERENNIALS 10% ANNUALS 90%	LESS THAN 10% OF AREA CULTIVATED	LOW	SCARCE	ALONG PERENNIAL STREAMS. VERY LITTLE DEVELOPMENT NEEDED	FLAT. GOOD MOVEMENT OF LIVESTOCK	GOOD AT SELECTED TIMES OF YEAR. NEEDS PROTECTION FROM CONTINUED USE	POOR. DISTANCE FROM VILLAGES AND LOW PRODUCTION
FLOOD PLAINS	69,800 HA (5%)	4,000 - 5,000 KG/HA	PERENNIALS 50% ANNUALS 50%	LESS THAN 10% CULTIVATED	HIGH	SCARCE	ALONG PERENNIAL STREAMS. NO DEVELOPMENT NEEDED	FLAT. MOVEMENT OF LIVESTOCK MAY BE HINDERED BY HIGH WATER	GOOD DURING DRY SEASON	POOR AREAS ADJACENT TO VILLAGES CAN BE USED
	1,396,000 HA									

TABLE 3.4. CRITERIA FOR EVALUATING LIVESTOCK POTENTIAL: MONTS MANDINGUES STUDY AREA

LAND UNIT	SIZE	RANGE VEGETATION		POTENTIAL LIVESTOCK PRODUCTION FACTORS					LIVESTOCK OPERATION TYPE	
		PRODUCTION	KIND	PRESENT AGRICULTURAL LAND USE	NATIVE FEED BASE	CROP AFTERMATH AVAILABILITY	LIVESTOCK WATER DEVELOPMENT	TOPOGRAPHY	TRANSHUMANT/ MIGRATORY HERDS	LOCAL/SEDENTARY HERDS
FLOODPLAINS	17,500 HA (5%)	6,000 - 7,000 KG/HA	PERENNIALS 50% ANNUALS 50%	30% OF AREA CULTIVATED	HIGH	ABUNDANT	NO DEVELOP-MENT NEEDED	FLAT LIVE-STOCK MOVE-MENT MAY BE HINDERED BY HIGH WATER	GOOD - CONTRIBUTES TO FEED BASE DURING DRY SEASON	GOOD, CAN BE USED BY LOCAL VILLAGES
TERRACES	69,300 HA (20%)	3,000 - 4,000 KG/HA	PERENNIALS 40% ANNUALS 60%	OVER 50% OF AREA CULTIVATED	HIGH	ABUNDANT	LIES ALONG PERENNIAL STREAMS. SOME DEVELOPMENT NEEDED TO MAKE FULL USE OF FEED	FLAT. LIVE-STOCK MOVE-MENT NOT HINDERED	MUST BE COORDINATED WITH AGRICULTURAL USE	GOOD. RESIDENT LIVE - STOCK PRODUCTION CAN BE INCREASED
UNDULATING PLAINS	69,300 HA (20%)	2,500 KG/HA	PERENNIALS 30% ANNUALS 70%	20% OF AREA CULTIVATED	MEDIUM	ABUNDANT	NEED CONSIDER-ABLE WATER DEVELOPMENT	UNDULATING, NO HINDRANCE TO LIVESTOCK MOVEMENT	MUST BE COORDINATED WITH AGRICULTURAL USE	GOOD IN VICINITY OF VILLAGES
DISSECTED PLATEAUS WITH NARROW VALLEYS	124,000 HA (35%)	300 - 400 KG/HA	PERENNIALS 5% ANNUALS 95%	NO CULTIVATION	LOW	NONE	NO NATURAL WATER AVAILABLE. MUST BE DEVELOPED	ROUGH WITH ANGULAR SIDE SLOPES, LIVE-STOCK MOVE-MENT GREATLY HINDERED	POOR. THIS IS AN IMPORTANT WATERSHED AND SHOULD BE PROTECTED	POOR.
DISSECTED PLATEAUS WITH BROAD VALLEYS	69,300 HA (20%)	2,000 KG/HA	PERENNIALS 5% ANNUALS 95%	OVER 50% OF AREA CULTIVATED	MEDIUM	ABUNDANT	SOME WATER AVAILABLE BUT IN POOR LOCA-TION. WATER MUST BE DEVELOPED	ROUGH WITH SMOOTH SLOPE SYSTEM. SOME HINDRANCE TO LIVESTOCK MOVEMENT	POOR	MODERATE USE CAN BE MADE OF AREAS CLOSE TO VILLAGES
	349,400 HA									

TABLE 3.5. CRITERIA FOR EVALUATING LIVESTOCK POTENTIAL: DIOILA STUDY AREA

LAND UNIT	SIZE	RANGE VEGETATION		POTENTIAL LIVESTOCK PRODUCTION FACTORS					LIVESTOCK OPERATION TYPE	
		PRODUCTION	KIND	PRESENT AGRICULTURAL LAND USE	NATIVE FEED BASE	CROP AFTERMATH AVAILABILITY	LIVESTOCK WATER DEVELOPMENT	TOPOGRAPHY	TRANSHUMANT/ MIGRATORY HERDS	LOCAL/SEDENTARY HERDS
PLAINS	130,000 HA (30%)	3,000 KG/HA	PERENNIALS 10% ANNUALS 90%	OVER 50% OF AREA CULTIVATED	HIGH	ABUNDANT	PERENNIAL STREAMS IN AREA. SOME WATER DEVELOPMENT	FLAT. NO HINDRANCE TO LIVESTOCK MOVEMENT	MUST BE COORDINATED WITH AGRICULTURAL USE	GOOD. CAN BE EXPANDED
UNDULATING PLAINS	65,000 HA (15%)	2,000 KG/HA	PERENNIALS 10% ANNUALS 90%	LESS THAN 10% OF AREA CULTIVATED	MEDIUM	SCARCE	SCARCE. WATER MUST BE DEVELOPED	ROLLING. NO / HINDRANCE TO LIVESTOCK MOVEMENT	GOOD.	MEDIUM
DISSECTED PLATEAUS WITH BROAD VALLEYS	173,500 HA (40%)	1,500 KG/HA	PERENNIALS 10% ANNUALS 90%	LESS THAN 10% OF AREA CULTIVATED	LOW	SCARCE	ADDITIONAL STOCKWATER IS NEEDED	ROUGH LIVESTOCK MOVEMENT GREATLY HINDERED	POOR	POOR. LOW PRODUCTION ON NON-CULTIVATED LANDS
TERRACES	21,700 HA (5%)	3,500 KG/HA	PERENNIALS 10% ANNUALS 90%	OVER 50% OF AREA CULTIVATED	HIGH	ABUNDANT	GENERALLY GOOD. A FEW DEVELOPMENTS NEEDED	FLAT. NO HINDRANCE TO LIVESTOCK MOVEMENT	MUST BE COORDINATED WITH AGRICULTURAL USE	GOOD CAN BE EXPANDED
WIDE FLOODPLAINS	43,400 HA (10%)	6,000 - 7,000 KG/HA	PERENNIALS 30% ANNUALS 70%	OVER 50% OF AREA CULTIVATED	HIGH	ABUNDANT	NO DEVELOPMENT NEEDED	FLAT. NO HINDRANCE TO LIVESTOCK MOVEMENT	MUST BE COORDINATED WITH AGRICULTURAL USE. GOOD DRY SEASON GRAZING	GOOD DRY SEASON GRAZING
	433,600 HA									

PHOTO 3.1

A. Shallow soils on plateau landforms are found in all Newlands Study Areas. They often support only annual grasses and forbs in the wet season. This example, from the Monts Mandingues escarpment, was acquired during the dry season (February, 1976).

B. This Plateau feature, similar to "A," shows heavy stands of annual grasses as seen in the wet season (September, 1976).

C. A "bouale," which is a depressional area with a shallow (less than one meter) restrictive soil layer. This photo, in the Dioila Study Area, was acquired in the dry season.

D. A similar "bouale," found between Sibi and Narena, has standing water, a seasonally common characteristic, supporting Dopatrium spp. in the wet season (September, 1976). The termite mounds are common to all bouales.

E. An example of extensive areas of annual grasses found on shallow (less than one meter depth) soils found in the Monts Mandingues and Dioila Study Areas in the dry season (April, 1976).

F. In the wet season (September, 1976), the shallow soils of the Monts Mandingues support a heavy growth of annual grasses.

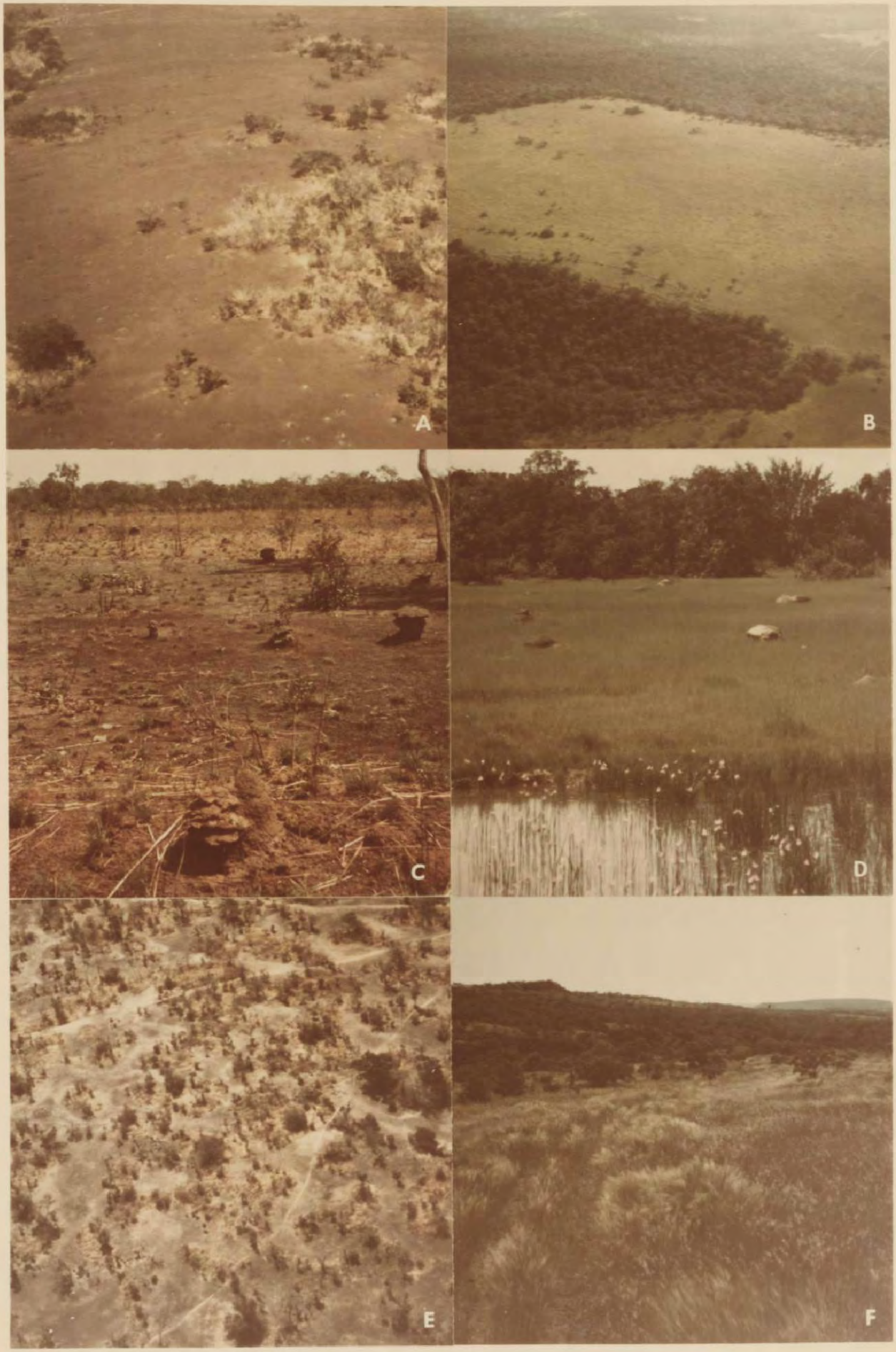


PHOTO 3.1

PHOTO 3.2

A. Rice is cultivated on floodplains and terraces of all Newlands Study Areas.

B. Diversified cultivation is practical throughout the Newlands Study Areas. Shown in this photograph, acquired north of Kita, are sorghum, peanuts, okra, and cotton crops. This combination of species provides soil nitrogen replenishment through the growth of legumes (peanuts).

C. Geologic fractures in dissected sandstone are important to groundwater exploration and development in the Kita Study Area.

D. Associations of grass savanna, woodland savannas and riparian communities in the Kita Study Area have high production potential for perennial grasses. This area also supports G. morsitans habitats.

E. This ground photograph shows a gallery forest association, a likely habitat of G. palpalis, surrounded by stands of important perennial grasses.

F. Along the road to Narena, in the Monts Mandingues Study Area, are stands of Diheteropogan ghasalense, which is an important livestock food throughout Mali.

PHOTO 3.2

3.3 DESCRIPTIONS OF LAND UNITS FOR THE NEWLANDS STUDY AREAS

Kita Study Area

The Kita study area is an extensive region of approximately 1,396,000 hectares, located north of Kita, between Bamako to the southeast and Kayes to the northwest. The southern boundary follows the railroad westward from Ginina to Badoumbe. The study area boundary extends northeast to Guetala, east-southeast to Niantelela and southeast via Guissoumale to Ginina as shown on the appropriate LANDSAT Image Base Map. Large portions of the Kita study area consist of forest reserves and national parkland which abound with wildlife and have sparse human settlement or other activity. The location and extent of these areas are shown on the Drainage and Forest Reserve Overlay corresponding to the Kita LANDSAT base map. The Land Units described in the following discussion correspond to the indicated areas on the Land Units Overlay.

Plains

a) Location and Geomorphic Characteristics

The Plains Land Unit of the Kita study area occurs in two separate areas. The larger area extends north of the railroad from Sebekoro to Warakoura, extending north along the Badinn-Ko River into the Forest Classe du Badinn-Ko. The smaller Plains Land Unit is located adjacent to the eastern boundary of the Kita study area. Both areas of this unit are relatively flat, having a local relief of 30 to 40 meters. The greatest differences in elevation occur between the lowest areas within the plains and isolated erosional remnants which are of limited areal extent. The larger Plains area is under intensive agricultural production and its LANDSAT appearance distinguishes it from adjacent Land Units. The Plains Land Unit along the eastern boundary of the Kita area is not so well defined on the LANDSAT imagery; however, some broad valleys in this area are easily delineated as the result of intensive agricultural activity and/or burning.

This Land Unit occupies an estimated 40 percent (approximately 558,400 hectares) of the Kita study area.

b) Vegetation and Soils Characteristics

The predominant soil type in the Plains Land Unit is a deep (2 meters) sandy loam in which illuvial clay has accumulated, at a depth of 60cm from the surface, to form an argillic B_t horizon. Cultivation is extensive, and it is the dominant land use on this soil. Herbage production is high, averaging about 4,000 Kg/ha. Native vegetation associations, in order of abundance, are savanna, tree savanna, and woodland. Perennial grasses are abundant, comprising 50 to 60 percent of the grass composition of non-cultivated lands.

Scattered throughout the Plains Land Unit are areas of shallow heavy clay soils, usually supporting annual grasslands. These soils are generally associated with laterite, and laterite crust and gravels are often observed at the soil surface. Herbage production is low (300 Kg/ha).

c) Land Use

At present, over 50 percent of the Plains Land Unit is intensively cultivated. Also, both the transhumant and local village populations utilize the grazing resource for their livestock.

Because of the high productive capacity of the land, and its favorably flat topography, both livestock production and cultivation could be increased in an integrated manner, or individually.

Dissected Plateaus (Broad Valleys)

a) Location and Geomorphic Characteristics

The Dissected Plateau (Broad Valleys) Land Unit lies in the northern portion of the Kita study area. Local relief is approximately 200 meters. Plateaus are dissected in several locations by major rivers such as the Badinn-Ko, the Kenieba-Ko, and the Baoule which have wide flood plains. A range of color tones (from yellow for cultivated and fallow lands and greens for dry season savanna lands) on the LANDSAT basemaps characterizes this Land Unit.

This Land Unit occupies an estimated 30 percent (approximately 418,800 hectares) of the Kita study area.

b) Vegetation and Soils Characteristics

The soils of the Dissected Plateau (Broad Valleys) Land Unit generally consist of shallow entisols. Entisols have a low level of soil profile development, reflected in a very weak differentiation of horizons. Soils are underlain by ferruginous crusts (cuirasses). The Broad Valleys have deep, well drainaged soils extensively used for agriculture.

Soils of the plateaus vary in depth, with open grassland occurring on shallower soils (25-50cm) and savanna occurring on deeper soils. The savanna and open grassland make up 60 percent and 40 percent respectively of the plateaus, with slopes commonly having a woodland association. About 40 percent of the grass composition are perennials. Native vegetation on the broad bottoms is woodland savanna with gallery forest (riparian woodland) along the drainages. About 60 percent of the grasses in these bottoms are perennials.

Herbage production varies from 700 Kg/ha on the shallow plateau soils to 3,000 Kg/ha on the deeper soils. Herbage production in the bottomlands is estimated to be 3,000 Kg/ha.

c) Land Use

Presently, about 15 percent of the area in the Broad Valleys is being cultivated. Little grazing use is being made of the area, which may be due to a lack of livestock water or to the reluctance of herders to take livestock into such a vast uninhabited area. A good native feed base is certainly being produced in this Land Unit and could contribute to increased livestock use.

Dissected Plateaus (Narrow Valleys)

a) Location and Geomorphic Characteristics

The Dissected Plateaus (Narrow Valleys) Land Unit occurs in two locations. The larger unit occurs in the northern portion of the Kita study area, west of the Konuko River; smaller units are found in the area of the Foret Classee du Bangassi. The larger Land Unit is characterized by erosional remnants or outliers averaging 575 meters in elevation. These outliers are bounded by steep-faced escarpments approximately 250 meters in elevation. A well dissected, rugged terrain area exists in the northeast corner of the Kita study area, averaging approximately 450 meters, with local relief varying by approximately 200 meters. Both of these areas appear as a pronounced dark green color with a rough photographic texture on the LANDSAT base maps. The "roughness" is indicative of the intense dissection which forms the extremely rough topography.

This Land Unit occupies an estimated 10 percent (approximately 139,600 hectares) of the Kita study area.

b) Vegetation and Soils Characteristics

The soils of the Dissected Plateau (Narrow Valleys) Land Unit generally consist of medium (50cm) depth entisols on the plateaus, and more shallow entisols on the slopes. A grass vegetation containing some perennials is supported on the plateaus. Woodland or tree savanna occurs on the narrow valley bottoms, and woodland occupies the slopes. Herbage production is approximately 800 Kg/ha on the plateau and 1,500 Kg/ha on the valley bottoms.

c) Land Use

Cultivation occurs in the wider of the bottomlands but it occupies less than 10 percent of the area. At present, there is little grazing use, and because of the rough topography and the lack of livestock water, it is doubtful that transhumant herds will make significant use of the area. Grazing by animals of the local villages could be expanded, and this is perhaps the best use for the area.

Rolling Hills

a) Location and Geomorphic Characteristics

Two areas of the Rolling Hills Land Unit occur; one along the northwestern edge of the Kita study area and the other along the southeastern

boundary. These areas are gently rolling with local relief of less than 100 meters in the southeastern section and less than 50 meters in the northwestern section. The more gently rolling northwestern section of this Land Unit appears as a light tonal green on the LANDSAT base maps. The southeast Rolling Hills area is characterized by reddish tones, indicating that a more heavily forested region exists in the southeast.

This Land Unit occupies an estimated 10 percent (approximately 139,600 hectares) of the Kita study area.

b) Vegetation and Soils Characteristics

In the northwestern area of this Land Unit, the soils have a moderately deep (50cm) soil profile, with a sandy loam to loam surface texture. An argillic clay horizon is encountered at approximately 35cm from the surface. The gently rolling terrain supports a savanna vegetation association with riparian woodland occurring along drainages. These soils are suitable for agriculture, although very little cultivation presently occurs. Herbage production is moderate (2,500 Kg/ha).

In the southeastern area of this Land Unit, the soil is deeper, although the same vegetation association occurs as in the northwest. Herbage production is higher, and is approximately 3,500 Kg/ha.

c) Land Use

The southeastern portion of the Rolling Hills Land Unit is intensively cultivated (over 50 percent of the area) while the northwestern portion is only lightly cultivated (less than 10 percent of the area). Both portions are presently lightly grazed by local livestock and forage resources are available for expanded livestock use; moreover, the terrain lends itself to easy livestock movements.

Terraces

a) Location and Geomorphic Characteristics

Terrace Land Units are adjacent to major stream courses in the west and northwest section of the Kita area. They occur principally adjacent to the Bakoye, and Baoule Rivers and to a limited extent along the Darouma River and its tributaries. The terraces are low relief platforms having an average elevation of approximately 200 meters and local relief variations of less than 30 meters. The Terraces appear as a bright yellow color on the LANDSAT base maps. This is indicative of possible past intensive grazing within these areas, a present grass vegetation cover, and sparse tree or shrub cover.

This Land Unit occupies an estimated 5 percent (approximately 69,800 hectares) of the Kita study area.

b) Vegetation and Soils Characteristics

Soil erosion is present on the Terraces and vegetation is rather sparse. It appears that these areas have at one time received heavy grazing pressures, for these soils should be supporting more vegetation than is now present. Most of the grass vegetation are annuals with a sparse tree or shrub cover.

c) Land Use

Small portions of the Terrace Land Unit are being cultivated, but this activity covers less than 10 percent of the area. These lands are contributing very little to the present feed base for livestock. Since they occur next to streams (an important source of livestock water) they are natural livestock concentration areas.

Wide Flood Plains

a) Location and Geomorphic Characteristics

Wide Flood Plains are delineated adjacent to many of the larger streams flowing through the Kita study area. They exist along the Bakoye, Darouma, Baoule, Badinn-Ko, Kenieba-Ko, Lekoni, Kenje, Moko-fabougou and many of their tributaries. They all are characterized by a bright red color on the LANDSAT base maps, indicative of a riparian tree canopy or gallery forest.

This Land Unit occupies an estimated 5 percent (approximately 69,800 hectares) of the Kita study area.

b) Vegetation and Soils Characteristics

These areas are inundated during the seasonal periods of high water levels. Marsh vegetation is predominant as well as riparian woodland associations. Alluvial silt and clay soils predominate.

c) Land Use

Currently, little use is being made of the Wide Flood Plains. A small amount of rice cultivation occurs, as well as some grazing in selected locations. Under good livestock management these areas could contribute to increased livestock production, especially if they are used for dry season grazing.

Monts Mandingues Study Area

The Monts Mandingues study area is located south and west of Bamako and comprises an area of approximately 349,400 hectares. It is bounded on the east by the Niger River, extending from Bamako to Koursale. The southern boundary extends from Koursale to Narena, the west boundary

from Narena to Negala. The railroad from Negala to Kati forms the northern boundary which extends east from Kati to the Niger River. The predominant feature in this study area is the Mandingue Plateau, but it also includes other landscape features and a variety of land uses. In the following discussion, each Land Unit corresponds to indicated areas on the Land Units Overlay corresponding to the Monts Mandingues Image Base Map.

Wide Flood Plains

a) Location and Geomorphic Characteristics

The Wide Flood Plains Land Unit in the Monts Mandingues study area consists of: 1) the active flood plain of the Niger River, and 2) the flood plains of large streams having a closed tree canopy and/or broad marshy areas. Both of these are easily recognizeable and delineated on LANDSAT imagery. The Flood Plains Land Unit includes those stream channels and their associated flood plains which are bounded by terraces.

Wide Flood Plains are delineated within the Niger River lowlands as well as in the Undulating Plains, Terraces, and the Dissected Plateau areas. The Koleko, Bararo, Samanko, and Kouloukouloudji Rivers have Wide Flood Plains, are tributaries to the Niger and flow in an east-southeast direction. Headwaters of the Dlada, Sebedyanafara, and Kalama, flow in a northward direction crossing the Dissected Plateau region in the extreme northern part of the area. The Simanko and Koba, both tributaries to the Baoule, flow in a northwest and westward direction, respectively, and drain the Dissected Plateau which makes up the central part of the Monts Mandingues area.

Wide Flood Plains are usually identified on the LANDSAT base maps by either characteristic rust-colored marshes of the Niger River, or bright red colors indicative of significant tree canopy within the other delineated stream channel flood plains.

This Land Unit occupies an estimated 5 percent (approximately 17,500 hectares) of the Monts Mandingues study area.

b) Vegetation and Soils Characteristics

Most of the Wide Flood Plain along the Niger River is inundated during high runoff periods. As the water recedes, marsh grasses and wetland species grow profusely producing herbage up to 7,000 kg/ha. There are small areas of clay soils containing dry season cracks that produce sparse vegetation. Dense patches of riparian woodland are found on the higher elevations of the Niger Wide Flood Plain, as well as along the other rivers and tributaries within this Land Unit, where soils are alluvial silts and clays.

c) Land Use

At present, there is little use made of this area except for a few small areas which are under cultivation. Potential uses of the area include:

1. More extensive agriculture, especially in the cultivation of rice within selected areas of the Niger Flood Plain.

2. A tremendous potential for grazing use, far greater than its limited size would indicate, provided the tsetse fly is controlled. With its high production it can provide feed for grazing animals during the dry season.

Terraces

a) Location and Geomorphic Characteristics

This Land Unit consists of broad Terraces having a local relief of 0 to 20 meters and an average elevation of 350 meters MSL. It extends along and adjacent to the Niger River in a northeast to southwest direction. The Terrace is approximately 3 kilometers wide in the northeast and broadens to more than 30 kilometers in width in the south and south-central part of the Monts Mandingues area.

These Terraces are relatively flat areas bounded on their river's edge by a gentle or entrenched river bank and on their western (upland) edge by an abrupt escarpment rising from approximately 380 meters in local elevation to approximately 500 meters. The Terrace Land Unit is easily differentiated on the LANDSAT base maps from the adjacent Flood Plain, Dissected Plateau and Undulating Plains Land Units. This is due to its characteristic yellow color indicative of intensive agricultural activity, as well as to the contrasting colors of this and adjacent Land Units.

This Land Unit occupies an estimated 20 percent (approximately 69,300 hectares) of the Monts Mandingues study area.

b) Vegetation and Soils Characteristics

The most extensive soil in this landform has a deep (at least 2 meters to bedrock) sandy clay loam surface texture grading into a clay at 50 cm. Much of these soils are under cultivation. This is a very productive soil, producing from 3,000-4,000 kg/ha of herbaceous vegetation, with perennial grasses comprising about 30 percent of the grass composition. Native vegetation associations are woodland and tree savannas.

Scattered throughout the Terrace Land Unit are small depressional areas with a heavy clay textured soil producing an annual grass vegetation of 1,000-1,200 kg/ha.

c) Land Use

Approximately 50 percent of the present land use is cultivation. The Foret Classe des Mandingues, where settlement and cultivation are restricted, is also located in this area. Several alternative land uses are possible because of the productive potential of the soil, and because of the favorably flat topography. It could, for example, support sustained

livestock production alone or in a combination with farming. The area of cultivation could be increased both in area and in intensity.

Undulating Plains

a) Location and Geomorphic Characteristics

The Land Unit of Undulating Plains is mapped in the southwest quadrant of the Monts Mandingues area. This area consists of rolling topography varying in local elevation between 370 to more than 600 meters MSL. It represents a transitional area between the Terrace Land Unit to its east and the escarpment-bounded Dissected Plateau to its west and north. The area can be separated from other Land Units by its alternating green, red, and yellow colors on the LANDSAT base maps, which is indicative of the presence of hills dissected by broad valleys containing agriculture.

This Land Unit occupies an estimated 20 percent (approximately 69,300 hectares) of the Monts Mandingues study area.

b) Vegetation and Soils Characteristics

The predominant soil in this Land Unit is an association of weakly developed soils (entisols) containing coarse elements, overlying ferruginous crusts (cuirasses). The soil profile is moderately deep (1 meter) with a sandy loam surface texture grading to a clay at about 40cm. Considerable gravel and some rock are found throughout the profile.

This soil is not optimal for agriculture, although cultivation is practiced in the better areas. Herbage production is approximately 2,500 Kg/ha, with perennial grasses comprising approximately 30 percent of the vegetation composition. Woodlands and tree savannas are the native vegetation associations.

c) Land Use

Agriculture is not an important use in this area, with only about 20 percent of the area being cultivated. Although the grazing potential is favorable at present, grazing is not significant. Many desirable perennial grasses are present which furnish feed over a much longer period of time than do annual grasses. Water for livestock does not seem to be a serious problem; however, as livestock numbers increase, more water facilities will need to be developed.

Dissected Plateaus (Narrow Valleys)

a) Location and Geomorphic Characteristics

Dissected Plateaus with Narrow Valleys make up a large part of the Monts Mandingues area. Most of the central part of the area is characterized by flat-topped table lands dissected by narrow stream valleys. Elevation in the area varies from 450 to more than 600 meters MSL. The

Dissected Plateau is bounded on its eastern and southern edges by an abrupt escarpment more than 150 meters in elevation which separates it from the Terrace and Undulating Plains below. The Plateau decreases gradually in elevation as one moves from the edge of the escarpment toward the north and northwest. On LANDSAT basemaps the tablelands are a pronounced emerald green color, and the narrow stream channels dissecting them are a bright red color.

This Land Unit occupies an estimated 35 percent (approximately 124,000 hectares) of the Monts Mandingues study area.

b) Vegetation and Soils Characteristics

These soils primarily consist of indurated materials eventually broken down into coarse debris, mainly as the result of physical weathering. Associated with these "soils" are ferruginous crusts (cuirasses). The shallow lateritic soil covers the flat plateaus which are low in forage production (200 Kg/ha) and which support only a light stand of annual grasses. The narrow valleys between the plateaus contain woodland, with Gallery Forest vegetation covering many of the streams.

c) Land Use

Presently, little use is being made of this area. Cropland cultivation is minimal. Forage production is low and the annual grasses last only a short period of time on the shallow lateritic soils. Water for livestock is a serious problem and livestock movement is hindered by the steep topography. Because of these severe limitations, it is doubtful that this area will ever contribute to a livestock program. Since this area is an important watershed, perhaps little or no use would be desirable in order to maintain the watershed in the best possible condition.

Dissected Plateaus (Broad Valleys)

a) Location and Geomorphic Characteristics

In the northern part of the Monts Mandingues area, Dissected Plateaus (Broad Valleys) were delineated as a Land Unit. Local elevation ranges from 420 to 550 meters MSL in this area. Broad valley bottoms containing intensive agricultural activities dissect the area; yellow and red colors on the LANDSAT base maps enhance the identification of these valleys and their associated land use. Interfluves in this area consist of broad flat-topped mesas of much greater areal extent than the more limited mesas in the Dissected Plateau (Narrow Valleys) region.

This Land Unit occupies an estimated 20 percent (approximately 69,300 hectares) of the Monts Mandingues area.

b) Vegetation and Soils Characteristics

These soils primarily consist of indurated materials eventually broken down into coarse debris. Associated with these "soils" are ferruginous crusts (cuirasses). Grass vegetation having a production of about 300 Kg/ha is supported on the shallow lateritic soils which cover

the plateaus. The valleys between these plateaus have productive, deep, alluvial soils, and they support a woodland vegetation. As these valleys widen, they are cultivated.

c) Land Use

Over 50 percent of the area in this Land Unit is being cultivated. Farming is confined to the broad valleys having the deep soils. Livestock potential is limited because of the low production of the non-cultivated lands and the steep topography.

Dioila Study Area

The Dioila study area (comprising approximately 433,600 hectares) lies east of Bamako, extending both northwest and southeast of the Niger River. The study area boundary extends from Koulikoro southeast to Dioila via Santigila, from the Niger River via Keninkou, west to Koula, and south to the Niger at Koulikoro, as shown on the LANDSAT Image Base Map. The Foret Domaniale Classee de Sousan is south and the large Foret Domaniale Classee de la Faya is southwest of the Dioila study area, both of which are shown on the Drainage and Forest Reserve overlay which corresponds to the Dioila LANDSAT Image Base Map. The Land Units overlay indicates the distribution and areal extent of features described in the following discussion.

Plains

a) Location and Geomorphic Characteristics

The Plains Land Unit is located in the central and southeast portion of the Dioila study area. This unit is characterized by a low local relief, of less than 30 meters, and thus represents a large flat lying area. The area is dissected by a few major rivers; the Baoule in the southeast corner, the Koba in the central part, and its tributaries in the Kounsigiko. On the LANDSAT base maps, interfluves adjacent to the Baoule and Koba Rivers are a light green, indicating that these areas are not intensively cultivated. The remainder of this unit has a brighter yellow color, indicating extensive cultivation.

This Land Unit occupies an estimated 30 percent (approximately 130,000 hectares) of the Dioila study area.

b) Vegetation and Soils Characteristics

The Plains Land Unit contains extensive areas of deep soils which would be classified as alfisols. Alfisols include loamy sands, loams, and clays in which illuvial clay has accumulated, at a depth of 60cm from the surface, to form an argillic B_t horizon. Cultivation is extensive, and herbage production is high (4,000 Kg/ha). The native vegetation association is a savanna or tree savanna with riparian woodland occurring along drainages.

Scattered throughout are entisols, which are small areas of shallow soils possessing a low level of profile development. These soils, locally known as "bowals" support only annual grass and have low (300 Kg/ha) production.

Also found in the Plains Land Unit are clay loam or clay soils, which contain coarse elements of gravel and rock. Because these areas are difficult to cultivate, they are left in their native vegetation. Herbage production is about 1,500-2,000 Kg/ha).

c) Land Use

Cultivation is by far the most extensive land use activity of the Plains area, occurring on over 50 percent of the area. Grazing by local village cattle also occurs. Grazing use by transhumant herds is difficult because of the extensive cultivation. The combined use of cultivation by villagers and grazing by local livestock seems to be feasible and could be expanded; topography is flat and offers no problem for livestock movement over the area.

Undulating Plain

a) Location and Geomorphic Characteristics

The Undulating Plain Land Unit is adjacent to and just north of the Plains area and extends almost the width of the Dioila study area. This unit, with approximately 100 meter local relief, represents slightly more rolling terrain than that of the Plains Unit. The average elevation for the area is 350 meters. In the north, there is an occasional erosional escarpment.

This Land Unit occupies an estimated 15 percent (approximately 65,000 hectares) of the Dioila study area.

b) Vegetation and Soils Characteristics

The principal soil type of this Undulating Plain Land Unit is an entisol, which here is a clay soil possessing a low level of soil profile development. The soils contain coarse elements within the profile, and they often overlie a ferruginous crust (cuirasse) which is a secondary formation enriched with residual or imported sesquioxides and subsequently indurated. A savanna or a tree savanna is supported, with woodland occurring in topographic depressions and along drainages. These vegetation types appear yellow on the LANDSAT base maps. The grasses are mostly annuals and herbage production is about 2,000 Kg/ha.

Small patches of shallow soils occurring throughout the Undulating Plains Land Unit support only annual grasses. Production in these areas is low (200 Kg/ha).

c) Land Use

Farming, in this Land Unit, comprises less than 10 percent of the area. Transhumant groups move through the area and make some use of the grazing resource. The area provides grazing only during the wet season, when annual grasses are green.

Dissected Plateaus (Broad Valleys)

a) Location and Geomorphic Characteristics

The Dissected Plateau (Broad Valleys) unit occurs both north and south of the Niger River, which bisects the northwest portion of the Dioila study area. This area is characterized by tablelands faced with steep escarpments and by dissecting rivers having broad bottomlands. Average elevation in the Dissected Plateau area south of the Niger is approximately 470 meters with local relief approximately 150 meters. North of the Niger the Dissected Plateau has an average elevation of about 400 meters with a local relief of 120 meters. On the LANDSAT base maps, the Plateaus are characterized by a rough textured green color. The rough texture indicates the intensive dissection of the plateaus and the green tone signifies an absence of a vegetative cover on the mesa tops during the time of year of the imagery (dry season of February).

This Land Unit type occupies an estimated 40 percent (approximately 173,500 hectares) of the Dioila study area.

b) Vegetation and Soils Characteristics

The Dissected Plateaus Land Unit contains soils consisting primarily of indurated materials, which when broken down due to the effects of physical weathering, become shallow sandy clay to clay soils. Associated with these soils are ferruginous crusts (cuirasses). Only annual grass vegetation is supported, and herbage production is about 200 Kg/ha. The slopes are steep and covered with woodland vegetation.

The soils in the broad valleys are deep, well-drained, and cultivated. Native vegetation associations in these valleys are generally savanna or tree savanna, producing about 2,500 Kg/ha.

c) Land Use

About 15 percent of the Broad Valleys are cultivated. Because of the rough terrain, uniform use of the forage is difficult by the transhumant herds which move through the area. Although some grazing use is made by village livestock, this grazing cannot be expanded significantly. This is because of the low production of the non-farm grasslands, most of which are annual grasses.

Terraces

a) Location and Geomorphic Characteristics

The Terrace Land Unit lies parallel and adjacent to the Niger River which flows through the northwest corner of the Dioila study area in a southwest to northeast direction. The Terraces are located between the Niger floodplain and the escarpments of the Dissected Plateau. Local relief on the Terraces is approximately 20 meters and the average Terrace elevation is between 300 to 320 meters. On the LANDSAT basemaps, the Terraces appear as a yellowish-red color, indicative of the presence of both agricultural activity and tree savanna.

This Land Unit occupies an estimated 5 percent (approximately 21,700 hectares) of the Dioila study area.

b) Vegetation and Soils Characteristics

The Terrace Land Unit contains deep, cultivated soils having a sandy loam surface texture. The natural vegetation is a tree savanna with riparian woodlands occurring along drainages. The grasses are predominantly annuals, and the herbage production is high (9,350 Kg/ha).

c) Land Use

Cultivation is extensive (over 50 percent of the area) on the Terrace Land Units. Because the area lies on one of the principal migration routes, transhumant herds graze the area, along with the local village cattle.

The recommended use of the area is that of a combination of farming and of local livestock operations.

Wide Flood Plains

a) Location and Geomorphic Characteristics

Wide Flood Plains were delineated along the Dilimba, Niger, Nyamanko, Kole, and Koba Rivers.

This Land Unit occupies an estimated 10 percent (approximately 43,400 hectares) of the Dioila study area.

b) Vegetation and Soils Characteristics

Along the Niger River, the Wide Flood Plain contains many marsh areas which display a rust-colored tone on the LANDSAT basemap. Most of the area is inundated during seasonal high water periods. The soils are primarily alluvial silts and clays. Small areas, which contain dry season cracks due to the desiccation of the clays, also occur and support little vegetation.

Other Flood Plains in this Land Unit contain both marsh and/or complete riparian tree canopies. The riparian tree canopies appear as a bright red color on the LANDSAT base maps.

c) Land Use

Rice cultivation is common on the Flood Plains, where the tendency has been toward increasing cultivation. However, these areas are also significantly important for livestock production. They have a high forage production (6,000-7,000 Kg/ha) and provide a good livestock feed base during the dry season.

3.4 TSETSE HABITAT DISTRIBUTION AND RECLAMATION PROSPECTS

LANDSAT IMAGERY IN RELATION TO TSETSE HABITAT DISTRIBUTION

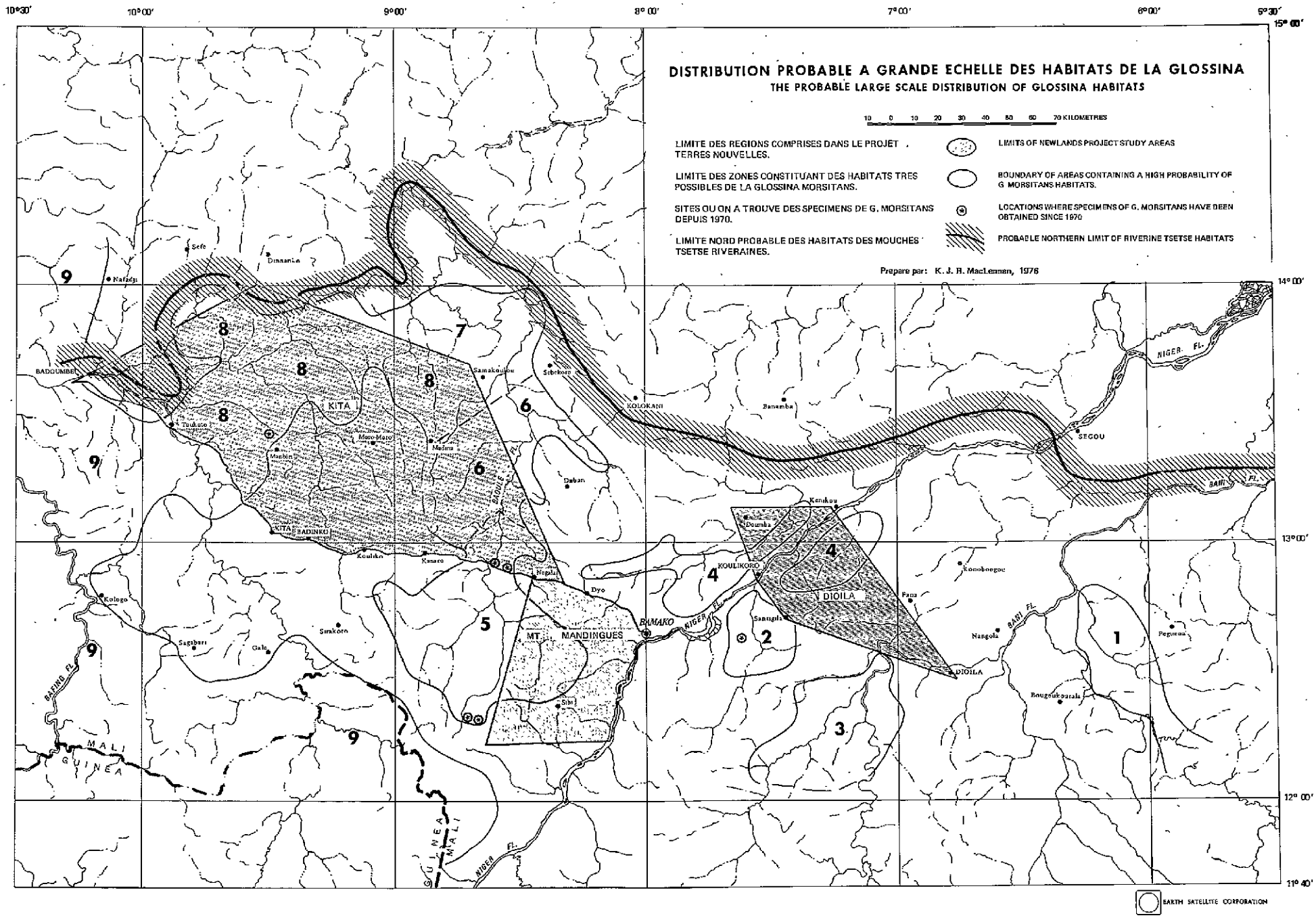
General Remarks on Vegetation in Relation to Tsetse Distribution

Tsetse fly distribution is locally most restricted and is most strongly orientated on specific features of the tree and shrub cover in the hot dry season (March/April in the Sudan and Northern Guinea vegetation zones). The common feature in the preferred habitats is the presence of an ample green foliage on the woody species at a time of year when other areas are showing a minimum of this feature, or are devoid of it.

For the riverine species, Glossina tachinoides and G. palpalis, the preferred habitat is located in riparian fringing forest for the latter, and in lesser riparian forest and green thicket for the former. For the savanna species, G. morsitans, the preferred habitats at this season consist of woodland or savanna woodland in the linear inter-zones around features such as flat topped hills or other rocky hills, along lesser drainages, at the foot of the slope near larger drainages and, in most extreme climatic conditions, the outer margins of riparian fringing forest.

In the Northern Guinea vegetation zone the most important, but not the only vegetational feature, is the Isoberlinia spp. woodland, particularly the linear zone between areas where this species is dominant and where it is not dominant. In the Sudan vegetational zone, this type of tree cover is lacking, and the preferred localities at the hot time of day are found in forest islands in river floodplains and in thicketed tree clumps associated with termite mounds and sometimes in dense stands of Acacia spp. It seems probable that in Mali the heavier woodlands associated with drainages and the footslopes of scarps, and particularly the tree cover of the larger fractures, can sustain G. morsitans populations, though this fact is yet to be confirmed by ground studies.

The common feature to much of the preferred habitats of both riverine and savanna tsetse in the earlier part of the second half of the dry season at the hot time of day, is an abundance of green foliage which is often in the actively growing state and which stands in sharp contrast to the majority of the area (about three-fourths) where this element is either not present, or is present to a much less degree than it is in the preferred localities. Tracts of country devoid of preferred habitats are not likely to be infested.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SEGOU
KOLOKANI
Samakouiou
Sebekoro
Banamba
Dabani
Kenikou
Doumba
Konobongou
Fana
Sanoula
Nangola
Pegueau
Bougoukourala
Siby
Dyo
Negala
Kasaro
Koulikoro
Kolokoro
Sagabari
Galo
Sirakoro
Nafadji
Sefe
Dimaandia
Badumbe
Tambaco
Mahina
Moro-Moro
Madina
Kouniakan
BADINKO
KITA
BAFING FL.
BAKOYE FL.
NIGER FL.
BANI FL.
MALI
GUINEA
EARTH SATELLITE CORPORATION

Map 3.1

Features Perceivable on LANDSAT

Since healthy green foliage is highly reflective in the near-infrared band (i.e. MSS-7) of LANDSAT, it could be expected that this would be indicated red or red-brown on false color LANDSAT imagery. Concerning the riverine habitats, this is indeed the case and an indication of the extent and density of the riparian forests is perceivable along the drainages on the imagery, though it takes some practice to differentiate between what is probably trees and what is probably green grass. But concerning the savanna habitats, distinctions are more difficult to perceive, there being more reflectance in the near infrared portrayed on the color LANDSAT imagery than could be accounted for by the actual existence of green foliage. However, with practice it is possible to distinguish between red loam of woodland and the yellow brown of deciduous tree savanna. Recently cultivated areas are indicated by pale yellow. Further development work, which falls outside the scope of the present project, could indicate whether the efficiency of this technology can be further refined.

The month of February was chosen because in other parts of West Africa the bush fires have passed and there is a maximum contrast in the leafed and non-leafed tree cover. As the dry season advances, the contrast decreases as the more deciduous species begin to flush with leaves. The moment when the imagery is acquired is fairly critical since interpretation is made more difficult on the one hand if the image is taken too soon after the burn, or on the other hand, too near the end of the hot seasons when less favored habitats are flushing with new leaves. Regenerating bush in farmland shows reddish-brown or pale yellow. On the present LANDSAT imagery, very recently burned areas are showing black. These progressively lighten through shades of dirty green with the age of the burn.

The LANDSAT Image Basemap showing the Monts Mandingues study area is dated about 18 days prior to that covering much of the Kita and Dioila areas. On the Monts Mandingues image, the proximity to the date of burn has limited the quality of interpretation possible. Other adjacent images are better in this respect, though in 1976 the best timing would have been in the first half of March. However, the choice of imagery has been limited by the fact that other timings are not available.

The other feature of importance is the indication from the imagery of the general intensity of human habitation and cultivation activity. Indications of extensive cultivation suggest those localities where the possibility of infestation by G. morsitans is lowest.

Commentaries on Individual Areas (Map 3.1)

Assessments follow on the probability of the existence G. morsitans habitats, to the degree that this is possible at the macro-reconnaissance level, in the belt of country in central Mali which contains the three project areas. The comments are based on what can be perceived from the

color LANDSAT imagery, on experience of tsetse infestations in equivalent vegetation zones elsewhere in West Africa, on a series of aerial survey flights conducted in 1974 and 1976, and on the very limited amount of ground survey work possible in the time available for this widely ranging reconnaissance which covers about 75,000 square kilometers.

Except where otherwise specified, the commentaries refer to the probable distribution of potential tsetse habitats. They do not indicate the actual presence or absence of infestation. This can only be determined by meticulous ground work by a body of men specially trained to perform this task. In assessing the probability of G. morsitans habitats, the discernible density of human occupation of land areas and the intensity of cultivation have been taken into account. This factor has little significance in relation to infestation by the riverine species, since riparian fringing habitats tend to persist in areas of dense human occupation and man-made habitats in the form of fruit orchards can replace, or even extend, the area of habitat available to the flies.

The Western Tsetse Belt (Includes the Kita and Monts Mandingues Study Areas)

A general indication of the area in which there is a high probability of G. morsitans habitats being present is indicated on map 3.1. This has been subdivided into blocks containing features of some degree of ecological similarity. To some extent, these conform to the Land Units described in Section 3.8.

Commencing with the upper reaches of the Baoule River contained in Block 5, it is clear that the vegetation is predominantly of the Guinea zone type. The major habitats are belts of woodland, and particularly the margins of these and tree savanna. These are orientated to a degree on drainage and topography and to features on hill slopes, (Photo 3.3A). The woodland component is most extensive in the center of the area within the forest reserves (Photo 3.3B). It is broken up substantially by cultivation towards the southwest and northeast. Also, infestation does actually extend down the scarp slopes into the country just north of Kinyema (north of Narena) and pockets of infestation are likely elsewhere in the undulating plain south of a line between Sibi and Narena (Photo 3.3C). The topography flattens out at the level of the railway and the tree cover consists of extensive tree savanna with belts of woodland.

The proportion of woodland to tree savanna declines markedly in the northern portion of Block 5, areas of Isoberlinia spp. becoming increasingly associated with the slopes of the surface drainage (Photo 3.3D). In this area, the favored hot season habitats (the interzone between woodland and tree savanna) probably do not amount to much more than 10 percent of the total area, though scattered throughout it and associated with drainages.

PHOTO 3.3

A. A view of the Monts Mandingues escarpment acquired during the dry season (April, 1976) shows examples of tree savanna and woodland along the scree slopes.

B. Monts Mandingues features in the Foret Classee de Monts Mandingues include scree slopes showing tree savanna, woodland, riparian woodland, and fringing forests. These areas provide habitats for G. morsitans, G. tachinoides, G. palpalis.

C. The woodland tree savanna and riparian woodland areas in the rolling hills between Sibi and Narena (Monts Mandingues Study Area) include pockets of tsetse infestation. This view was acquired 8 kilometers west of Sibi, looking northwards in August, 1976.

D. In the northern portion of Block 5, there is increasing orientation of Isoberlinia woodland onto drainage slopes, as shown in this examples of the Baoule River. Such areas are favored dry season tsetse habitats.

E. Northwards on the Baoule River, there is a progressive thinning of upland tree savanna with heavy woodland persisting along the river banks.

F. Along the Baoule River, in the western portion of the Kita study area (Block 8), possible tsetse habitats are principally in the riparian woodlands which occur along both the rivers as well as numerous sandstone fractures.

G. Many of the Kita study area fractures in dissected sandstone support dense Borassus spp. palms and other woodland which may sufficiently provide primary tsetse habitats.

PHOTO 3.3

Proceeding northwards through Block 6, the tree savanna on the plains thins progressively and the amount of woodland diminishes, though heavy woodland and riparian forest continues on the main river (Photo 3.3E). The interfluve to the west also contains habitats. The western margin is not defined with confidence. The imagery suggests extensive woodland in this area suitable for infestation, but west of the line mapped there is also an indication from the imagery and from the survey flights, that the extent of cultivation between the Kassaro to Madina and Badinn-Ko to Moro-Moro roads may be inhibiting infestation. It is quite possible that actual infestation here does extend further to the west than the probability line indicated on the map. Conversely, east of the Baoule River a degree of doubt exists as to whether there is enough habitat to sustain G. morsitans infestations, except in the zone around the Kodian River and the broken country to the north of this.

In Block 6 outside the Kita study area, primary G. morsitans habitats further diminish in extent as the vegetation takes on more the aspect of Sudan zone type. The degree to which this is actually infested will depend on climatic factors in the dry season. In Nigeria, for example, most of the tree savanna which is seen here near the Baoule would not support infestation, but it would be unwise without further field study to indicate that the area is probably lacking in habitat since climatic stress factors are possibly less in Mali than in equivalent areas of Nigeria.

In Block 7 between the two northern loops, the country south of the Baoule River contains drainages and other topographical features which sustain tree cover that is probably sufficient to harbor G. morsitans (Photo 3.3E), possibly constituting about 5 percent of the area overall but scattered throughout it. If these features turn out to be infested, there is a possibility that similar features north of the river may be sufficient in extent to harbor infestation, especially between the two loops in the Foret Classee de Kongosanbougou. South of the Baoule River the possibility of infestation is greatest along the Kenie and Filikiba Rivers and increases towards the upper reaches as these approach eastern Block 8.

It seems unlikely that habitats capable of sustaining G. morsitans exist within the northern-most loop of the Baoule River. Should this judgement be found to be in error, this would modify substantially the judgements which have been made so far.

Proceeding westwards, downstream from the most northern loop, habitat possibilities seem minimal until about 9°10W when features characteristic of Block 8 approach the river (Photo 3.3F). The features common to all areas marked "8" are the existence of varying degrees of dissected sandstone plateau and the occurrence of fairly numerous fractures (Photo 3.3G). Beyond the fact that specimens of G. morsitans have actually been obtained in this type of country, nothing is known of its capability to sustain G. morsitans. The writer, in particular, has no experience of this type of country elsewhere in Africa. Many of the

fractures and other drainage features are occupied by Borassus palms, which may be quite dense, and there are also belts of woodland (ferisols not determined) associated with scarps (Photo 3.3G). The actual extent of these components which might be functioning as primary habitats is variable, though widely distributed in all Blocks 8. The southern part of eastern Block 8 has probably been sufficiently heavily cultivated to inhibit infestation. It is likely that the favored components are not sufficient in amount to make possible the uniform infestation of all country in all Blocks 8. It seems highly probable that some of this country in the vicinity of the Kenieba-Ko River is infested. Habitat possibilities diminish near the Baoule River, but areas upstream on the Keniebo-Ko River and around it, appear on the imagery to have a high degree of probability of infestation. Similar conditions exist on the adjacent un-named tributary to the north.

At about the point where the Baoule River re-enters the Kita study area, it widens to a substantial inundation zone with a meandering water channel for a distance of about 20 kilometers. This is the only section of the river with such a feature, elsewhere the course is incised with a minimum of inundation zone. This flood plain might turn out to be an important habitat feature. Downstream of this feature to the junction with the Bakoye, G. morsitans habitat features become minimal, except on some of the tributaries, where the probability is considerably higher.

The southwestern Block 8 contains an abundance of Block 8 features described earlier which appear capable of sustaining G. morsitans infestations, and the flies have actually been found to be present near the Tali-Ko River north of Manbiri.

Until the contrary is proven, it is necessary to regard all Blocks 10 as containing habitats for G. morsitans. Between northern Block 10 and northern Block 8 from the foot of the escarpment and east to beyond the Kouala River, the aerial survey flightline indicated a rolling plain and rolling hills covered mainly by sparse tree savanna increasing in density towards the east, which is probably uninfested. If the quality of rangelands justifies this, the Kita project perimeter could be extended westward to part of the escarpment. However, in Block 8 east of the Darouma River fracture and slope habitats again become prominent and the tree cover increases in density (Photo 3.4A).

The most important feature to emerge from these reconnaissance assessments (yet to be confirmed by ground surveys) is the probable existence of a large tract of country roughly centered on Kita where G. morsitans habitats are of low probability. From Kita, southeast to Narena, over the point where the Kita to Gale Road crosses the Bakoye River, and then over Siraakoro and the southwestern portion of the Mandingue escarpment, the incidence of cultivation apparent from an aerial survey suggested an intensity of farming activity sufficient to seriously reduce the availability of G. morsitans habitats. In the portion of Block 10 in the Republic of Guinea, human population density is sufficiently low to suggest a high probability of G. morsitans infestation, in marked contrast to the corridor indicated between Sirakoro and Narena. There is some suggestion from the imagery to confirm this assessment, though there is an element of doubt concerning the status in the middle of the corridor and the width of the corridor.

PHOTO 3.4

A. West of the Kita Study Area, the sparse tree savanna covered rolling hills are probably not infested. Proceeding east, however, increasing density of tree cover and presence of fracture features in the northwestern portion of the Kita Study Area suggest possible harboring of G. morsitans.

B. The dissected plateaus north of the Niger River near Koulikoro (Block 4) contain habitats capable of sustaining G. morsitans.

C. The tree savanna and woodland of the Foret Domaniale Classee de La Faya, along the La Faya River, are known to be infested by G. morsitans. This photo shows heavy woodland along the lower La Faya River as seen in September, 1976.

D. Potential man-made tsetse habitats occur within mango plantations which are extensive along the terraces and floodplains of the Niger River near Bamako. This view south of Bamako was acquired in the dry season (February, 1976).

E. Riverine tsetse habitats are widespread in the three study areas. In this photo from the Diola Study Area, tree canopy during the dry season (February, 1976) is not complete and adjacent land has been cleared for cultivation.

F. In this photo from Monts Mandingues study area, a continuous Gallery woodland along the drainage provides year-round tsetse habitat.

G. The dissected sandstone fractures of the Kita Study Area provide adequate woodland habitats for both riverine and savanna tsetse.

PHOTO 3.4

The Central G. morsitans Habitats (Includes Dioila Study Area and Blocks 2, 3, and 4 of Map)

The two Blocks 4 are located in broken country on each side of the Niger River. They contain habitats capable of sustaining G. morsitans populations (Photo 3.4B). No actual infestation is on record concerning these areas and although some doubt exists as to whether the extent of habitat is sufficient, they have to be regarded as infestable until ground surveys show the contrary to be the case.

Block 2 contains the Foret de la Faya, which is known to be infested by G. morsitans, specimens having been obtained by Dr. Challier of OCCEE Centre Muraz, Bobo Dioulasso. This is less broken country and the interfluve tree cover is a medium, sometimes sparse, tree savanna with woodlands associated with drainages (Photo 3.4C), but quite small in total amount. The fact that this sort of country can be infested, indicates the possibility that Blocks 4 could be infested and a high degree of probability that Block 3, which contains the Foret de Soussan, is also infested since it is clear that this contains a greater proportion of suitable habitats over a larger area.

The Eastern G. morsitans Belt

Block 1, east of the Bagoe and Bani Rivers, is the only area east of Bamako which is indicated as being infested on the international distribution maps of 1953. LANDSAT imagery confirms the existence of probable habitats in the area delineated on Map 3.1. The interfluve between the eastern Banifing River and the Bagoe River is heavily utilized, but the valley of the Upper Banifing and of the Koba Rivers, in particular, still appears to retain G. morsitans habitats. It has to be assumed that this infestation is still extant until the contrary is proved by ground survey.

Riverine Tsetse Habitats

Riverine tsetse habitats are widespread in the three study areas (Photos 3.4E, 3.4F and 3.4G). The probability that they are infested can be judged from the density of riparian forest, indicated as red on the LANDSAT imagery. It can be assumed that areas of less-dense canopy will be occupied seasonally during the wet season with a retraction to heavier tree cover in the dry season.

The macro-distribution of riverine species has been set out on the large-scale maps of Rickenbach (Centre Muraz, Bobo Dioulasso) and in Mulligan and Potts (The African Trypanosomiases, 1970), and because of the association with human sleeping sickness, the information is more extensive than that on G. morsitans.

In the reviewed area of Map 3.1, the Niger River is recorded as infested to near the vicinity of Segou and the Bani River to near Djenne, in the northeast. The northern Baoule River is indicated as not infested north of about 13°30 on the northward-running stretch. To the west, the

northern limit is to the north of Manbiri and Bafoulabe. Both G. tachinoides and G. palpalis are recorded to the limits mentioned in the northeast, the former existing a little further than the latter. To the west, G. tachinoides is not recorded north of latitude 13° at longitude 9°, nor west of longitude 11° at latitude 12°, this being the western continental limit for this fly. Thus, riverine tsetse infestations are not indicated as being present on the northern Baoule River from about 13°30' latitude until the region roughly corresponding with the junction with the Bakoye River.

Analysis of LANDSAT imagery and the aerial survey flights both suggest that G. tachinoides habitats exist for the whole length of the Baoule River, even on the northern loop, except for intermittent stretches. These analyses also suggest that a variety of habitats suited to both species of riverine tsetse are present in localities having heavy riparian type vegetation in the valley bottoms of the dissected sandstone plateaus wherever these occur. Additionally, in the Kita study area, some exceptional features exist. These are:

1) The wider belts of riparian vegetation on the Darouma and Baoule Rivers for distances of about 20 kilometers where the northern boundary of the Kita study area crosses these rivers.

2) A similar stretch of vegetation on the northern part of the Kenieba-Ko River.

3) The heavy riparian cover which is present along many of the larger fractures in this area (Photo 3.4G).

It seems possible that these could provide a basis for infestation by both riverine and savanna tsetse. The existence and location of these features can be perceived on LANDSAT imagery.

Whether all of these apparently suitable vegetational features retain infestation by riverine tsetse, will depend on the degree to which surface moisture or water is present for all or most of the year, a fact which cannot be assessed by survey at the reconnaissance level. Thus, it is possible that apparently suitable habitats may not be infested, or may be uninfested for part of the year, if the moisture requirement is not available. This moisture requirement is not essential for G. morsitans infestations.

Potential for Tsetse Eradication Activity in the Newlands Study Area

When examining the feasibility of tsetse extermination activity, the following general points have to be considered:

1) The availability of a technique which can achieve extermination.

2) The existence of a defendable perimeter.

3) The economic justification.

Technique

The only technique which has led to the extermination of tsetse flies over a substantial area in West Africa is the highly restricted application of persisting insecticides to preferred hot season resting places. In Nigeria, this approach had been applied to 194,250 square kilometers of a project area of 260,000 square kilometers during a period of 22 years. The reviewed area in Mali on Map 3.1 covers 100,000 square kilometers. The Nigerian technique is very selective indeed, involving a single application of pesticide to a narrow band within the 10 percent or less of the infested area which contains the most favored hot season resting places of the flies. Application is by teams of ground sprayers, using knapsack sprays, occasionally supported by motorized mist blowers. The knapsack sprayer rather than the mist blower is favored wherever possible because of the precision which is possible in the placement of the insecticide deposit, thus reducing the impact on non-target organisms. A single application only is required to achieve extermination. Environmental side effects attributable to the pesticide have been monitored over a period of years and found to be minimal. The program has been augmented by helicopter applications, but these are not as efficient as ground spray and have a wider impact on non-target organisms. The only pesticides available which achieve extermination by ground spray are dieldrin and DDT, both these compounds being in current use. The helicopter applications are using dieldrin or endosulphan. Many alternative pesticides have been tried, but all have failed to achieve extermination, though the very recent availability of a semi-persisting synthetic pyrethroid at last offers some prospect of being able to discontinue the use of the chlorinated hydrocarbons. In the meantime the program proceeds, as it has from the commencement, using DDT and dieldrin with some endosulphan. There is no doubt that the efficient application of ground spray techniques to the infestations described in the study area of Map 3.1 in Mali would also achieve extermination, though behaviorial studies on Glossina are necessary to confirm that patterns follow those in Nigeria and to familiarize field staff with the fundamentals of the technique.

The only other method which has led to the extermination of tsetse flies over a substantial area is through repeated blanket spray applications by fixed-wing aircraft to the whole of the infested area. This method has been used to eradicate infestation in Zululand in the Republic of South Africa and the area has remained fly-free since 1954.

The latter technique has been progressively refined and has now reached the stage where five or six applications by fixed-wing light aircraft are made at very low dosages (six to twelve grams endosulphan per hectare, ULV by rotary atomizers, producing a droplet of VMD 30μ). Unfortunately, despite the developmental work involved since the early 1950's, there is no substantial area which has remained fly-free for sufficiently long for a judgement to be made that the method unquestionably achieves extermination, and it is also clear that aspects involving the biology of the flies, rather than the mechanisms for dispensing the pesticides, require some further study. The method has been developed on the eastern side of the continent where conditions of infestation are

somewhat different. It has only recently been attempted in Nigeria where, for a variety of reasons, the first attempt did not succeed. It seems likely that further developmental work will lead to the extermination of tsetse by this method in flat terrain.

It can be foreseen that the repeated aerosol technique may be difficult to apply in part of the infested area of Mali which is located in broken country. The aircraft must fly very close to the tree canopy and conditions of adiabatic inversion must exist. It is hazardous to attempt this method in broken country. The duration of utilizable inversion is erratic in Nigeria, being limited, when it does occur and if night flying is prohibited, to the period around dawn and dusk if Harmattan winds are not blowing. Elsewhere, it has been possible to extend the period of utilizable inversion by night-flying. Some countries prohibit this and it is not possible in broken country.

The sterile male release method is being developed in several localities, but is yet to be proven on a large area basis. Many problems have yet to be surmounted but there are prospects for success. A basic requirement is the reduction, through the utilization of non-persisting pesticide applications, of the natural male population. The only feasible approach, at present, to obtain this requirement, is the dispersal of non-persistent aerosol applications by air and the constraining factors mentioned above will also apply.

At the present state of knowledge, the only proven technique available for use in Mali is the highly restricted single application of persisting pesticide either by knapsack sprays or helicopter. By the time a project is implemented, alternative approaches might be available.

Perimeters

Until actual infestations have been mapped (rather than the probability of habitats described in this report) it cannot be indicated that a defendable perimeter exists anywhere or not. But there are some general points which can be made.

It is more sound in stategic terms to progress into infestations from areas known to be fly-free. If this precept is followed, land reclamation from tsetse infestation would proceed southwards from the fly-free areas to the north to natural limits which may exist further south or to buffer zones, of limited extent in relation to the area reclaimed, from which infestations are periodically removed.

Costs

Since no project can be specifically formulated at this reconnaissance stage, detailed area costings cannot be made. But it can be indicated that in the kind of country concerned, overall costs for everything excluding expatriate personnel costs would probably run at roughly U.S. $0.95 to $1.20 per square kilometer reclaimed, if either a single,

Kita Study Area

This study area has very interesting possibilities. There is sufficient diversity in habitat probabilities to suggest that the detailed study of the actualities of tsetse distribution and tsetse ecology might lead to the formulation of a progressive tsetse eradication program, advancing in phases protected by buffer zones from which infestation is periodically removed. Such a program would open up new pasture resources accessible to transhumant cattle. Moreover, the tsetse belts here are devoid of cattle during the rains. There is an indication that, if further study suggests that an eradication program is feasible, this would alleviate a little of the pressure on northerly pastures and provide space for the development of improved husbandry techniques. The remarks apply equally to savanna and riverine tsetse infestations present.

An essential aspect of activity in the Kita study area is that it would have to extend beyond the limits of the actual study area. One important component of this aspect is to review the savanna tsetse habitat status presently assigned to the large block of country around and to the south of town of Kita. This may well contain relict G. morsitans populations, but they probably could be eliminated easily as part of tsetse reclamation activity in the western tsetse belt, once they have been located and delineated by careful ground survey.

The Monts Mandingues Study Area

This is the most heavily infested of three Newlands study areas by both groups of tsetse. The area falls into two major components consisting on the one hand of Dissected Plateaus, and on the other of Niger Terrace or Flood Plain. The savanna tsetse problem mainly involves the Plateau lands, though it does extend down into the northern part of the Undulating Plain Land Unit and perhaps elsewhere. The elimination of the savanna tsetse infestation might be justified ultimately if this infestation poses a substantial perimeter threat to progress made in the Kita study area. It is certainly possible that, taking a 20 year perspective, it would be financially advantageous to eliminate the source of a reinvasion threat rather than to continue to control it in a buffer zone, regardless of the actual value of the land resource which habors the source of reinvasion pressure.

Riverine tsetse habitats are present in the Monts Mandingues study area (in the Terrace lands and Niger Flood Plain), and the pasture resources here are good or have special qualities. There appears to be scope for increasing both the transhumance usage and the livestock production by settled communities, should the riverine tsetse infestation be removed. Infestations on the Niger River could be eliminated as well as those in the tributaries, but canoe traffic on the river, from upstream, would provide a major channel for reinfestation. It might be possible to control this. A point of considerable importance is the series of rapids downstream from Bamako which provide a useful barrier to canoe

traffic, and where tsetse habitats are minimal in extent. They would assist in the isolation of a project on the Niger River downstream of Bamako but this, unfortunately, would do little to suppress the very considerable, peri-domestic trypanosomiasis problem arising from infested mango plantations in and around the urban areas. At this stage of study, it is not possible to take assessment of perimeter weakness on tributaries any further, but clearly these points should be kept in view in the future.

Recommendations and Suggestions for Future Work

Ranking of Areas

The Kita study area offers the greatest scope for the utilization of Newland resources through the elimination of tsetse infestations. There are other important considerations affecting the other two study areas, and the country outside them, which have already been discussed. Further field work on tsetse distribution, consideration of animal and human health aspects, and of land use intentions will indicate whether the Monts Mandingues study area or the Dioila study area should receive priority after the Kita study area. Land use decisions by the Government of the Republic of Mali will substantially influence the use of reclaimed land for livestock production in the Kita study area.

Further progress in the formulation of tsetse reclamation activity is limited by the absence of a local field capability to survey tsetse very restricted application of persisting pesticide is used or if the repeated aerosol blanket technique is used assuming expenses at 1976 rates. In those areas where riverine habitats are of minimal extent, the single placement of a persisting deposit might cost less than this per square kilometer of area reclaimed, except in major river flood plains where it would cost more.

The Study Areas

Dioila Study Area

Blocks 4, which both extend into the study area, are possibly not now infested with savanna tsetse (G. morsitans). If they are, infestation could easily be eliminated by restricted ground spray.

Infestations more probably exist currently in Blocks 1, 2, and 3, but these lie outside the study area and are not having a major impact on this area which is already extensively used both for dry and wet season grazing. The elimination of these infestations, if they exist, though important in a different context, would not open up new grazing resources in the Dioila study area.

Riverine tsetse infestations (G. palpalis and G. tachinoides) are associated with both the Niger and the Bani drainage systems. The Dioila area of itself would not justify a major tsetse reclamation program on either of these rivers, but there are other very important reasons for keeping such a possibility in view for the future.

distribution and study the behavior of local tsetse populations. The creation of this capability has several stages:

a. The definition of the staff requirement which is essential.

b. The definition of support facilities required by these personnel to enable them to function in the field.

c. The acceptance by the Government of the Republic of Mali of the specific existence of such an organization.

d. Financial provision for the funding of the unit.

e. The training of the personnel at various grades, once agreement has been reached on the structure of the unit, finance has been provided for it, and the personnel have been recruited.

Once this capability exists, progress can be made on mapping the actual distribution of tsetse infestations. Studies can also commence on behavioral features of infestations such as seasonal fluctuations in density and local distribution, day and night resting behavior, and the field performance of insecticide formulations which will make possible the development of specific reclamation projects. The field capability is also essential in order to establish baseline data before anti-tsetse activity commences, to monitor changes which take place during the reclamation activity, and to monitor the extermination status inside project areas and in protective buffer zones.

The data from which the large area distribution maps which exist have been prepared, are probably available at the Centre Muraz at Bobo-Dioulasso. Such data could expand the assessment given in this report, and where possible, could provide the precise definition of places where specimens of Glossina spp. have actually been found.

3.5 SUMMARY

The selection of the Kita Region as a test site for tsetse control operations was based upon three principal considerations:

1. Livestock potential
2. Propriety for testing tsetse control operations
3. Current land use

EarthSat and its consultants, Mr. Currier and Dr. MacLennan, believe that the selection of the Kita Region is a sound and proper decision, based upon the professional judgment in several scientific disciplines (entomology, range management, remote sensing, soils science, and geology) of the entire EarthSat group. The basis for the selection of Kita is tabulated in Tables 3.2, 3.3, 3.4, and 3.5, presented on pages 3-10 through 3-13. These tables represent the process by which the selection was made and record the essential weighing factors used to evaluate the geomorphologic, ecologic, and cultural data utilized in the selection process.

As can be seen in the referenced tables, the Kita region surpassed both Dioila and Monts Mandingues in several considerations. The single most important feature for Kita, however, is the presence of large areas of perennial grasslands. Also of importance is the fact that the terrain is distributed in such a pattern as to facilitate a reasonable infrastructure development.

The Dioila region presently posesses a fair infrastructural system, but, because of its relatively intensive agriculture and man-altered tsetse conditions, it cannot be considered as a principal contender for tsetse programs.

The Monts Mandingues region posesses some of the necessary attributes for selection purposes. However, its rugged terrain and lack of infrastructure (with the exception of the Sibi-Narena road) make it undesirable as a test site.

It is recognized, of course, that subsequent tsetse control operations will be conducted in all three regions and that by such time as the implementation of general tsetse control has begun the criteria used in this selection are likely to be changed significantly.

As requested by OMBEVI and USAID, the Newlands studies were conducted at the reconnaissance level. It is recognized and recommended that further, definitive, range management and entomological studies be conducted by OMBEVI and CVL. It is understood that these programs will be effected by implementation of future Mali II efforts, and we sincerely believe that the baseline data herein provided will be essential to the conduct of those programs.

4. TRAINING

4.1 REMOTE SENSING TRAINING COURSE

A training course on Remote Sensing of Natural Resources was presented to OMBEVI in French by Earth Satellite Corporation under the direction of Mr. Bill Van Tries, in Bamako, Mali, from October 18 to 23, 1976. This program, presented in two parts, was designed to offer the Malian participants an information package on remote sensing principles and technology.

Part I of the Training Course discussed remote sensing using satellite imagery, primarily from LANDSAT, but also from Skylab orbital systems. Computer enhanced LANDSAT imagery, with its superior resolution and greater information content, was also discussed in some detail. Applications of the use of this imagery were presented for West Africa, in terms of 1) the inventory of natural resources; 2) rangeland management; 3) agriculture; 4) soils; 5) geohydrology; 6) mineral exploration; and 7) wildlife management.

A three phase methodology in natural resource studies was emphasized, with satellite imagery comprising a reconnaissance level Phase I. Phase II should consist of the use of larger scale aerial photographs for a more detailed analysis of areas selected from examination of the satellite imagery. Ground verification in key areas should be conducted in Phase III.

The discussions were accompanied by photographic illustrations, and examples of photographically enhanced LANDSAT, digitally enhanced LANDSAT, and Skylab imagery were available for individual analysis by each participant. Written material to accompany each lecture, translated into French, was distributed to serve as a reference tool, and a permanent record of the information presented (see Table 4.1).

Fundamentals of Remote Sensing

Mr. Jack Palgen (currently on leave of absence from EarthSat and serving as Senior Advisor to the African Remote Sensing Program of the United Nations Economic Commission) conducted much of the Part I proceedings which included the following topics:

- The electromagnetic theory of remote sensing. The nature of electromagnetic radiation in terms of its wave properties was described. Also, the narrow and broad bands of the electromagnetic radiation, used by contemporary remote sensors, were discussed.

- The principles of "pictorial perception" including a discussion on the elements of size, shape, shadow, tone or color, texture, pattern, site, association, and resolution were described.

- The "multi" concept as applied to the acquisition and analysis of remote sensing data including multi-station photography, multiband photography, and multi-date, season, or year photography was discussed.

- Photographic systems for remote sensing. These systems produce images in which a latent image is produced by the transformation of incoming light by a film-camera system. The spectral sensitivities of black-and-white and color aerial films were discussed. The theory of color photography was presented including additive-subtractive color and the film constructions of conventional, high resolution, and color infrared films.

- Non-photographic systems were discussed in terms of: radiative signal generation (passive); signal emission from a target; energy propagation through the photographic medium; sensing of the energy signal; and signal processing and transmittance. Signal receipt by a ground receiving station was also described.

- The LANDSAT (non-photographic) and Skylab (photographic) orbital satellites. (Skylab was discussed in less detail because of the comparatively minor role it presently plays in applied remote sensing.) Skylab photography does exist, however, for large regions of Mali.

  Advantages of high orbital sun-synchronous imagery were noted, and these included advantages of synoptic coverage, uniformity of illumination, quasi-orthographic and repetitive photo coverage capability. Limitations noted included cloud cover, resolution, and problems of limited tape recorder capacity.

  LANDSAT was discussed in terms of the vehicle itself, its sensor systems (multispectral scanners, RBV cameras), its orbital parameters, lifetime, and output format.

  The LANDSAT products discussed were: bulk and precision processed imagery; transparencies and prints; color products; computer magnetic tapes, and color composite products.

  A photographic tour of the NASA Goddard Space Flight Center facilities in Washington, D.C. where the LANDSAT information is received, was accomplished through a photographic presentation. Mr. Palgen discussed the various stages of the information transfer which lead to the production of an image. He described data pre-processing in terms of photo-optical and photo-digital techniques, and he discussed EarthSat's capability to manipulate the information contained on the magnetic tapes to produce high quality images.

- The role of remote sensing information systems in National development. The integration of remote sensing techniques into resource management and development programs was discussed. Mr. Palgen explained that remote sensing offers techniques of acquiring a wide variety of information necessary for resource management, exploration, inventory, and environmental monitoring, often with reduced time and cost, because some of this information may be acquired simultaneously. The state-of-the-art of LANDSAT applied to Africa at National levels was investigated.

- Economic Commission for Africa. The structure of a LANDSAT utilization system at the United Nations level was described.

- Ground receiving stations in Africa. Mr. Palgen stressed the concept, role, and future of these systems in Africa.

Natural Resources Analyses

Dr. Linda Zall, formerly an instructor of photo-geology and photo interpretation at Cornell University, now with Earth Satellite Corporation, discussed current applications of the use of satellite imagery in the interpretation of natural resources. This portion of the Training Course covered the following topics:

- Geohydrology. Dr. Zall discussed the preparation of groundwater exploration guide maps from the interpretation of satellite imagery. A multi-stage sampling program, consisting of a three phase methodology, where satellite imagery is to be used in Phase I, was described that can provide valuable regional guides for groundwater prospecting.

  The exploration guide maps produced in Phase I eliminate many of the areas having little potential for groundwater and focus attention on those areas that are most favorable. This minimizes the necessary Phase II aerial photographic and geophysical efforts and Phase III field efforts, and therefore substantially decreases the cost of any regional groundwater exploration program.

- Mineral exploration. The unique ability of satellite systems to acquire imagery depicting large portions of the earth's surface enables geologists to characterize large, widely separated tectonic provinces - an important first step in the search for mineral deposits. Moreover, once having located a proper geologic environment, investigators can map the tectonics, structure, and lithology of the area and delineate those subareas which generally favor the economic accumulation of minerals. Satellite imagery becomes a powerful tool in any regional mineral exploration program.

- Soil surveys. Dr. Zall discussed a methodology whereby regional soil surveys can be accomplished using satellite imagery. In essence, the derived soils are identified on the basis of parent material, climate, topography, and time. Basic lithologies and topographies are identifiable on the imagery. The satellite imagery should then be used to determine where larger scale conventional stereo aerial photographs, and subsequent field work should be used to refine the soil type determination.

Range Management

Part II of the Training Course was concerned with range management, in terms of inventory and resource mapping, production, utilization, and management. Mr. Wilbur F. Currier of EarthSat (former Chief of the United States Forest Service, Office of Range Improvement and Management) conducted this session. This part of the program was presented primarily for OMBEVI participants. Much of Mr. Currier's discussions are included in his books Allotment Analysis Handbook, 1976, and Structural Range Improvement Handbook, USDA/Forest Service, 1972, copies of which were distributed to OMBEVI at the end of the session. These volumes describe the range management theories, techniques and applications that are presently being used in the semi-arid western United States and which are also used in Australia and South America. They are significant from the standpoint of their immediate practical application to range resources, because they describe climatic, vegetative, and soil conditions analogous to those existing in Mali. Mr. Currier described these techniques in relation to his field work in the Dilly region of Mali with the Earth Satellite Range Team.

Before Mr. Currier began his discussion of range projects, Dr. Zall explained the methodology and techniques used in stereo aerial photographic interpretation. She described the utilization of five important keys (topography, drainage, erosion, vegetation, and photographic tone) which eventually lead to the identification of both landforms and soils from the study of the photographs. This discussion was considered an important background for Mr. Currier's presentation, for the majority of the range inventory and resource mapping was performed before the commencement of field work, in the Earth Satellite Corporation's Washington offices, using the aerial photographic techniques she described. Preliminary landform and vegetation maps used in field verification were prepared for the Dilly region from the interpretation of both stereo black-and-white, and stereo color infrared photography.

The original aerial photographic maps used during the Dilly field work, and examples of the stereo aerial photographs and satellite imagery were available for participant use. Throughout his presentation, Mr. Currier referred to these references as he explained their use.

The Training Course terminated with an open session where participants from all the invited Malian organizations could address specific questions to the EarthSat Training Course team.

AIDSAT Activities

Concurrent with AIDSAT activities in Mali, EarthSat personnel were utilizing remote sensing data as practical resource management tools in the Dilly and Newlands regions.

Mr. David Sprague, Director of the AIDSAT team then visiting Mali, perceived the implication of this coincidence and invited EarthSat to participate in AID/GRM discussions of AIDSAT. The interest generated by the discussions among the GRM workers, Mr. Sprague and Mr. Van Tries, resulted in the invitation of interested GRM scientists to attend Part I of the OMBEVI Training Course. Subsequently, 21 representatives of various organizations attended the Training Course. Because the participants represented diverse technical interests, attendance at the Training Course varied.

The enthusiasm and interest of those attending largely concerned the application of remote sensing technology to the resource management problems of Mali. The EarthSat presentation was somewhat modified and expanded to respond to the diversified interests of the additional attendees.

The following organizations were represented in Part I of the Training Course.

OMBEVI: - Dr. Maiga, N. Sow, Digo Tembele, M. Dabo, Jacques Beaudrais (FAO)

Direction Nle Agricult: - Sekeu Sissoko, Cheickna Toure, Yaya Togola

Genie Rural: - Dagakoro Samake, Ousmane Ouologuem, Mamadou Sylla, Drissa Berthe

I.E.R.: - Hamidou Doumbia

I.R.A.T. (Soils): - Bassirow Keeta

Eaux et Forets: - Sidiki Sanogo, Salif Kanoute, Pierre Toumani Traore, Yacuba Doumbia, Mady Ketta, Yacouba Ketta, Bather Kone, Ismail Berthe

Elevage: - Alassane Diaoure, Moulaye Diallo, Moussa Coulibally, Madame E. Togola

O.A.C.V.: - Abdoulaye Traore

C.M.D.T.: - Zana Vincent Dembele

Hte. - Vallee: - Tidiani Diarra

Protection Semences: - Moussa Sissoko, Zoumana Soumtera

Geologie et des Mines: - Ousmane Abdou Maiga, Diallo Mamadou Moctar

SOTUBA: - Dr. A. Sow, K. Fylla

TABLE 4.1

Listing of Materials and References Distributed to Training Course Participants

Remote Sensing of Natural Resources

I. Technical Principles of Remote Sensing

A. Excerpts from the Bamako Compendium (adopted from the text by R. Tessier and A. Alouges). General Principles of Remote Sensing.

B. The Technology of Remote Sensing, by L. Von Wambeka, C.C.R. Brussels.

II. LANDSAT (ERTS) Remote Sensing of Natural Resources

A. Centers for Processing and Treatment of Earth Resources Satellite Data, by Jack Palgen.

B. Principal Annotations on LANDSAT Images, by Jack Palgen.

C. Satellites and Their International Value for Resources, by Dr. Charles Weiss, World Bank.

D. Conceptual Base for an African LANDSAT Photolab, by Bal Reed.

III. Photo Interpretation

A. Photo Interpretation, by Dr. Linda Zall, Earth Satellite Corporation.

B. Photo Interpretation, by Max Guy, Institut Francais du Petrole.

C. Landforms and Aerial Photographs, by V.C. Miller, Resume.

D. Soil Inventories by Aerial Photographic and Satellite Imagery Interpretation, by Dr. Linda Zall, Earth Satellite Corporation.

E. Soils and Aerial Photographs, by A.P.A. Vink.

F. Vegetation and Aerial Photographs, by P. Rey, Faculte des Sciences de Toulouse (France).

G. Groundwater Exploration, by Dr. Linda Zall, Earth Satellite Corporation.

IV. Rangeland Management - The Method Used by Earth Satellite Corporation

A. Landforms, Vegetation, and Soils of the Dilly Region, by Mr. Wilbur Currier and Dr. Linda Zall.

B. Allotment Analysis Handbook, 1976. United States Department of Agriculture, U.S. Forest Service.

C. Structural Range Improvement Handbook, 1972. United States Department of Agriculture, U.S. Forest Service, Mr. Wilbur Currier.

V. Remote Sensing in Africa

A. Remote Sensing in the Sahel: Remote Sensing Applications to Resource Mapping, by J.B. Bale, D. Conte, D. Goehring, D.S. Simonett, Earth Satellite Corporation.

VI. Remote Sensing Terminology and General References

A. Photogrammetric Terminology: English-French, French-English.

B. General Geologic Bibliography for West Africa.

VII. Miscellaneous

1. Remote Sensing and Ecography, by A. Alouges and C. Rosett.

2. Remote Sensing of Natural and Artificial Ecosystems: Is it Justified and Possible?, by G. Lang et al.

3. Methodology of Some Integrated Studies, by C.S. Christian and G.A. Stewart.

4.2 REMOTE SENSING INTERNSHIP PROGRAM FOR MALIAN SPECIALIST IN RANGE MANAGEMENT

Dr. Aboudalaye Sow of SOTUBA and OMBEVI, Bamako, Mali, participated in a two-week Remote Sensing and Range Management Internship program in July of 1976. The Internship occurred at the Washington, D.C. offices of Earth Satellite Corporation. During this period, he interacted with Earth Satellite staff scientists, who represent such diverse fields as agriculture, soils, ecology, biology, land use, geology, geography, computer technology, and photographic science. Dr. Sow examined EarthSat's unique approach to the solving of natural resources problems by our use of multi-disciplinary teams of professionals analyzing various types of remotely sensed data.

Dr. Sow received a similar, but more detailed introduction to Remote Sensing than was presented during Phase I of the Training Course for OMBEVI. The first week was devoted to Remote Sensing principles, techniques, and applications. Dr. Sow was able to evaluate the merits of integrated resource surveys involving Remote Sensing. He also received a conducted tour of the NASA Goddard Space Flight Center, and visited with officials at the United States Agency for International Development.

The second week of the U.S. based training was devoted primarily to Mali Range programs. Dr. Sow assisted EarthSat scientists in the interpretation of the aerial photographs and Space Imagery for Dilly and Newlands.

Although the AID contract did not specify a requirement for this internship, EarthSat believed that Dr. Sow's presence at EarthSat's U.S. offices and laboratory could greatly contribute to the overall value of the contract, and this was concurred in by OMBEVI and USAID. In addition to the training received by Dr. Sow, his technical contributions to the project during his two-week stay in the U.S. are considered to be a key factor in the project's success.

APPENDIX A

Report by Dr. A. Sow on Mali: Newlands Project - 1976 -

Editor's Note: Dr. Abdoulaye Sow, SOTUBA, has provided substantial assistance and valuable contributions to Earth Satellite Corporation's efforts in the present Mali livestock program, for which we are grateful. Dr. Sow was a teacher, as well as a student, of EarthSat's Training Program; he accompanied all EarthSat field trips, lending botanical knowledge and guidance, received an internship in EarthSat's offices in Washington, D.C. and had additional experience in Bamako and in the field. Mr. Sow has assembled a considerable amount of environmental and resource information not readily available or published regarding the Newlands project areas. EarthSat is pleased to include this material in our report in its original French version.

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I. INTRODUCTION

Dans le cadre du projet Terre-Nouvelles deux sorties furent effectuées en deux points de la zone concernée. La première sortie qui a eu lieu le 11 mai 1976 a été un survol d'une heure d'une partie du Plateau Mandingue. Ce survol a permis à la mission de passer rapidement en revue les possibilités sylvo-agro-pastorales de cette zone. La seconde sortie a été effectuée dans la région de Fana. Elle a duré une demi-journée en Land Rover. Au cours de cette seconde sortie l'occasion a été donné à la mission de constater les possibilités d'élevage dans une zone où intervient en grande partie la C.M.D.T.

Les Terres-Nouvelles ayant été subdivisée en trois régions à savoir : le Monts Mandingues, Dioila, Bamako-Est et Kita, il s'agissait de proposer le choix de celle qui serait la plus propice à une action d'élevage. Mais les trois zones sont infestées de glossines, agents vecteurs de la Trypanosomiases. Ceci est un facteur très gênant pour l'élevage. Dans ce cas une action d'assainissement de la région choisie s'imposerait avant toute autre. Parmi les moyens de lutte à envisager figure l'utilisation des insecticides classiques tels que : DDT, Parathion, Malathion, Aldrine, Endrine, Dieldrine, HCH, etc. - Mais l'emploi de ces produits présente un danger certain surtout pour la faune aquatique, en particulier les poissons qui constituent l'une des principales sources de protéines pour les populations riveraines des cours d'eau de la région.

II. SITUATION GEOGRAPHIQUE DES TERRES NOUVELLES

La région considérée est située entre 12°25' et 14°20' delatitude nord, 6°25' et 10° de longitude ouest. C'est a'dire qu'elle peut s'inscrire dans un quadrilatère de 325 Km de long sur 200 Km de large. Ce territoire de 65.000 Km^2 a été subdivisé en trois sous-régions qui sont : le Monts Mandingues au sud-ouest de Bamako, Kita à l'ouest, Bamako-Est à l'est.

III. LE RELIEF

Le relief est dominé par les Monts Mandingues dont les chaines affectent l'allure d'un immense compas largement ouvert sur le nord-est. L'altitude moyenne des chaines atteint 450 m à Koulouba et plus de 700 m au sud-ouest de Sibi.

IV. HYDROGRAPHIE

Deux réseaux hydrographiques se partagent la zone. Il s'agit du Niger et quelques-uns de ses affluents au sud-est, et du système Baoulé-Sénégal au nord-ouest et à l'ouest. Mais la partie centrale de la

région qui est dominée par les hauteurs mandingues constitue le haut bassin du Baoulé. Seuls quelques cours d'eau de faible importance dans cette région appartiennent au réseau hydrographique du Niger. D'ailleurs la zone de partage des eaux est très près du cours de ce fleuve.

V. GEOMORPHOLOGIE

Pour la région qui nous concerne la stratigraphie générale présente les caractéristiques suivantes :

a. Socle précambrien

Il affleure dans la partie méridionale de la région. Il se compos de roches métamorphiques et de granites qui sont pour la plupart d'origine sédimentaire.

b. Ere primaire

On y distingue les deux séries suivantes :

1. Le Cambrien, qui est caractérisé pour la plupart du temps par des schistes. Cette formation disparaît sous les grès ordoviciens qui recouvrent la majeur partie du pays.

2. L'Ordovicien, qui est caractérisé par un conglomérat de base constitué par des galets de quartz puis des dépôts détritiques qui se sont consolidés sous forme de grès. Les grès ordoviciens sont recouverts d'une couche de latérite plus ou moins épaisse et fortement bauxitique.

VI. CLIMATOLOGIE

Le climat, dans l'ensemble est du type soudanien et présente deux saisons nettement tranchées à savoir :

a. Une saison humide qui va de juin à fin d'octobre avec un maximum des précipitations en août.

b. Une saison sèche allant d'octobre à juin et qui se subdivise en :

1. Une période sèche et froide qui va de décembre à fin février.

2. Une période sèche et chaude allant de mars à fin mai.

Les principaux facteurs climatiques qui ont été étudiés pour deux stations extrêmes (Bamako et Kita) permettent de calculer :

- l'indice d'aridité de De Martonne
- Le quotient pluviothermique d'Emberger
- L'évapotranspiration potentielle

Et de tracer le diagramme ombro-thermique de Gaussen ainsi que le climogramme pluviothermique. Toutes ces études ont été effectuées en comparaison avec d'autres stations du Mali, afin de mieux saisir la physionomie réelle du climat de la région des Terres-Nouvelles.

6.1 Principaux facteurs climatologiques

Tableau 1

Station	Temp. Moy. annuelles en °C	Moyennes Maxima du mois le plus chaud	Minima du mois le plus froid	Hauteurs pluviométrieque moyennes annuelles
Bamako	28,1	32,4	25,4	1079,8
Kita	28,0	32,8	25,5	1137,5
Sikasso	27,3	30,9	24,3	1337,0
Nioro du Sahel	28,6	34,1	22,7	676,1
Tombouctou	29,3	34,3	22,6	220,4
Tessalit	28,7	35,5	20,1	88,8

6.2 Indice d'aridité de De Martonne

L'indice d'aridité de De Martonne est donné par l'égalité :

$$I = \frac{P}{T + 10} \qquad (1)$$

dans laquelle P est la pluviométrie moyenne annuelle en mm, T la température moyenne annuelle en degrés centigrade, est d'autant plus faible que le climat est plus sec.

6.3 Quotient pluviothermique d'Emberger

Le quotient pluviothermique est donné par la relation.

$$Q = \frac{P \times 100}{(M+m)(M-m)} = \frac{100\ P}{M2 - m2} \qquad (2)$$

Tableau 2

Station	I	Q	Observations
Bamako	28,3	266,880	Soudanien
Kita	37,0	267,301	Soudanien à tendance Soudano-guinéenne
Sikasso	48,9	366,985	Soudano-guinéen
Nioro du Sahel	23,2	104,410	Sahélien
Tombouctou	7,5	33,200	Nord Sahélien
Tessalit	22,8	10,370	Saharien

6.4 Mois biologiquement secs pour la végétation

Les mois biologiquement secs pour la végétation se situent dans la période allant de Novembre à fin Mai parce que la quantité de pluie recueillie est inférieure au double de la température : $T > 2P$.

VII. SOLS ET PEDOGENESE

Faute de résultats d'analyses pédologiques, on peut se contenter d'une simple énumération des différents types de sols et leur pédogénèse.

7.1 Plaines alluviales

Les sols sont de nature silico-argileuse plus ou moins latéritifiés. Ils constituent pour la plupart du temps des terrains de culture. Ils proviennent de la désagrégation de roches siliceuses, en particulier des grès, en mélange avec des apports argileux d'origine hydrique.

7.2 Formations alluvionnaires fluviatiles

Le long des cours d'eau et dans les bas-fonds humides on rencontre des dépôts alluvionnaires sable-argileux ou argile-sablonneux en mélange, en proportions variables, avec des limons plus ou moins riches en matières organiques. Ces formations présentent une certaine importance surtout si la pente est faible ou nulle. Quand celle-ci est trop forte les éléments fins sont entraînés par lessivage horizontal laissant sur place du sable plus ou moins grossier.

7.3 Glacis de piedmont ou glacis d'érosion

On le rencontre au bas des pentes gréseuses où le sol est transformé en une cuirasse parfois épaisse de plusieurs mètres. Si le terrain présente une certaine pente, les eaux pluviales opérent une action d'érosion qui aura pour résultat de transformer la cuirasse en blocs de grosseur variable. On en est alors en présence d'une formation alluvionnaire dont les éléments sont de plus en plus petits à mesure qu'on descend la pente. Si au contraire il s'agit d'un replat, on est en présence d'un terrain bowalisé recouvert d'un dépôt alluvionnaire de faible importance. Les bowés sont caractérisés par la présence des termitières champignons à Cubitermes sp, du sable plus ou moins grossier.

7.4 Terrains des hauteurs

Les masses grésseuses soumises aux actions d'érosion (température vents, eaux pluviales) se désagrègent et donnent des sols plus ou moins caillouteux. Sur les hauts sommets les terrains sont transformés en une puissante cuirasse plus ou moins bauxitisée. Elle est presque dépourvue de végétation.

VIII. VEGETATION

On rencontre deux types de savanes dans la région des Terres-Nouvelles. Il s'agit de la savane soudano-guinéenne occupant la partie sud de la région et le Plateau Mandingue. Elle constitut le prolongement septentrional du district forestier nord-guinéen. Elle serre comme dans un étau, la seconde savane qui est du type soudanien dans son ensemble. La répartition de la végétation dans chacune des deux flores est la suivante.

8.1 Savane soudano-guinéenne

Elle est caractérisée, à l'origine par la présence de Sô Isoberlinia, du Uaperca somon et du Monotes kerstingii. Cette savane est si dégradée en certains endroits par les feux et les défrichements de culture que seul l'Isoberlinia semble être parfois le seul critère valable de classification de ce type de savane. La végétation de la région se repartit comme suit :

a. Formations planitaires exondées. C'est parfois une savane boisée à allure de forêt claire. La formation est alors plus ou moins fermée, avec un sous bois pauvre en herbacés. Dans sa forme dégradée, elle présente de petits massifs séparés par une savane riche en graminée. Ce type de savane occupe les plaines alluviales, les vallées, etc.

La composition d'une telle formation dans son aspect original est donnée au tableau 3 ci-dessous.

b. Formations planitaires inondées. Les formations planitaires inondées comprennent les ripicoles longeant certains cours d'eau et la végétation des bas-fonds humides ainsi que les phreato-feet.

1. La végétation ripicole. Le tableau 3 ci-dessous donne la composition de cette végétation.

Tableau 3

Strate	Famille	Nom scientifique
Arbustive	Legumineuses papilionacées	Pterocarpus santalinoides
	Moracées	Ficus capensis Ficus gnaphalocarpu Ficus platyphylla
	Rhamnacées	Zizyphus mucronata
	Phyllanthoidés	Securinega spp.
	Apocynacées	Funtumia africana
Lianes ligneuses	Asclepiadacées	Parquetina nigrescens Oxystelma bornuense Leptadenia heterophylla
Herbacée	Graminées	Leptadenia hastata
	Andropogonées	Sorghastrum trichopus Hyparrhenia rufa Vetiveria nigritana Pobeguinaea arrecta Andropogon africanus Andropogon gayanus Schizachyrium nodulosum Schizachyrium palustre

2. Zone d'inondation des cours d'eau et bas-fonds humides : Cette formation porte les mêmes graminées que précédemment et quelques autres espéces données au tableau ci-dessous.

Tableau 4

Strate	Famille	Nom scientifique
Sous-ligneux	Onagracées	Jussiaea erecta
		Jussiaea stemoraphe
		Jussiaea linearis
		Jussiaea repens var diffusa
Herbacées	Rubiacées	Borreria filifolia
		Borreria stachydea
		Borreria chaetocephala
	Acanthacées	Hygrophilla senegalensis
	Scrofulariacée	Micrargira filigormis
		Striga astatica var lutea
	Graminées	Oryza longistaminata
		Echinochloa pyramidalis
		Andropogon shirensis

Parmi les phreato-feet on peut citer :

Sphaenoclaea zeylanica
Sphaenoclaea dalzieli
Nymphaea lotus
Nymphaea micrantha
Ceratophyllum demersum
Ipomaea asarifolia
Ipomaea aquatica

c. Galeries forestières. Les galeries forestières de la région peuvent être assimilées à des irradiations de la forêt dense ombraphile semper virent et à la forêt dense semi décidue. Leurs caractéristiques morphologiques sont les suivantes : sous-bois sombre à humidité quasi-permanente ; présence de certaines espèces constamment vertes. Quand la pente du terrain est trop forte pour permettre la retenue de l'eau, la forêt-galerie se transforme en un véritable mélange botanique où cohabitent des espèces ombrophiles et semi-décidue (formation mésophile).

1. Forêts-galeries à Berlinia heudolothiana et Uapaca guineensis : C'est une formation mésophile souvent située le long des cours d'eau temporaires où l'humidité du sol n'est nullement permanente. Le substrat pédologique est de nature sablonneuse ou sablo-argileuse situé sur conglomérat de base à galets de quartz. Le tableau 5 ci-dessous donne la composition de la végétation.

Tableau 5

Strate	Famille	Nom scientifique
Arborée et arborescente	Legumineuses	
	Cesalpiniées	Berlinia heudelotiana Erythrophleum guinéense
	Euphorbracées	Uapaca guineensis
	Myrtacées	Sizygium guinéense
	Guttiféres	Garcinia ovalifolia
	Palmacées	Raphia vinifera Raphia sudanica Elacis guineensis
	Ochnacees	Ochna membranacaea
	Linacées	Ochthocosmus dewerei
	Rhizophoracées	Anisophylla laurina

A la périphèrie de la forêt galérie on reconcontre les espèces suivantes citées au tableau 6.

Tableau 6

Strate	Famille	Nom scientifique
Arborée et arbus-	Césalpiniées	Isoberlinia doka Isoberlinia dalzieli Daniellia oliveri
	Dipterocarpées	Monotes kertingü
	Papilionacées	Pterocarpus erinacens Pterocarpus lucens Pterocarpus santalinoides
	Capparidacees	Boscia angustifolia Boscia salicifolia
	Oleacacées	Ximenia americana

Herbacée	Graminées	Beckeropsis uniseta Andropogon tectorum Pennisetum subangustum Panicum repens Acroceras amplectens
	Cyperacées	Scleria depressa
	Acanthacées	Nelsonia canescens Dicliptera vertcillata
	Papilionées	Desmodium salicifolium

2. Forêts-galéries à Cola Laurifolia et Entostemia senegalense : Ces formations se rencontrent sur sols alluvionnaires où l'humidité est quasi-permanente, le sous-bois presque sans lumière. Si le courant d'eau est faible, des herbes aquatiques telles que le Fuirena umbellata peuvent pousser au fond. Cette cyperacée joue un rôle très important dans le cycle biologique de la Simuli agent vecteur de l'onchocercose.

Le tableau 7 donne la composition de telles galéries forestières.

Tableau 7

Strate	Famille	Nom scientifique
Arborée et arborescente	Sterculiacées	Cola laurifolia
	Euphorbiacées	Entostema senegalense
	Cesalpiniées	Berlinia heudelotiana
	Flacourtiacées	Flacourtia flavescens Oncoba spinosa
	Moracées	Ficus vallis Schoude Ficus capensis
Lianes ligneuses	Apocynacées	Strophanthus gratus Baissae multiflora
	Aracées	Culcasia scandens
	Opiliacées	Opilia celtictifolia

	Mimosacées	Entada mannü
	Asclepiadacées	Gongronema latyfolium
	Menispermacées	Cissamepelos mucronata
Lianes herbacées	Smilacacées	Smilax kraussiana
	Dioscoreacées	Dioscoraea hurtiflora Dioscoraea bulbifera Dioscoraea prehensilis

Partout les formations planitaires sont en recul devant les feux périodiques qui brûlent la savane et les défrichements de culture. La disparition de certaines espèces telles que Monotes kerstingii et même du Uapaca Somon, est la preuve certaine de la destruction de la savane soudano-guinéenne.

N'était la présence de certaines espèces à grand pouvoir colonisateur grâce à leurs stolons, (par exemple Isoberlinia doka et Daniellia oliveri) il serait très difficile de fixer aujourd'hui les limites de cette zone soudano-guinéenne.

3. Formations vallicoles exondées

Sur les hauteurs Mandingues les cours d'eau dévalent de 100 à 200m, provoquant et isolant des tables de roche qui ménagent entre elles des vallées plus ou moins profondes. Celles-ci portent une végétation dense, de même nature que les plains on y rencontre des espèces telles que Paquistella pobequiniana et Manilkara multinervis, certainement aussi Monotes kerstingü. Sur sols humides on rencontre le Borassus flabellifer var aethiopum indiquant le terme de dégradation d'une formation plus hydrophile.

8.2 Formations Orophiles

Sur les hauteurs mandingues les plateaux gréseux, et les thalwegs et les escarpements portent des espèces rares, relictes d'une veille forêt longtemps disparue de la plaine. L'étagement d'une telle forêt se fait de la manière suivante :

Tableau 8

Strate	Famille	Nom scientifique
Arbustive	Cesalpiniées	Guiburtia copaifera
	Malpighiacées	Acridocarpus plagioterus
	Hernandiacées	Gyrocarpus americanus
Herbacée	Graminées	Diheteropogon hageurupii Pennisetum subangustum Backeropsis uniseta Andropogon tectorum Chasmopodium candatum

Tableau 9

Strate	Famille	Nom scientifique
Abrorée et arbustive	Papilionée	Pseudocedrella kotschyi
	Meliacées	Ostryoderis smithmanii
	Anacardiacées	Pseudospendias microcarpa
	Rutacée	Teclaea grandifolia
	Ebenacées	Diospryos
Herbacées	Graminées	Beckeropsis uniseta
	Ampelidacées	Cissus quadrangularis
	Orchidacées	Eulophia sp.

8.3 Savane soudanienne

La savane soudanienne se caractérise par la présence du Karité - vitellaria et du Parkia biglobasa. La végétation se repartit comme suit :

a. Formation des pénéplaines basses
b. Formations des plaines alluviales
c. Bas-fonds humides
d. Formations ripicoles
e. Galeries forestières

8.4 Pénéplaines Basses

Substrat caillouteux ou callavions sur cuirasse. La végétation se compose somme suit :

Tableau 10

Strate	Famille	Nom scientifique
Arborée et arvustive	Sapotacées	Vitellaria paradoxa
	Mimosacées	Parkia biglobosa africana
	Mimosacées	Prosopis africana Albizzia chevalieri Albizzia malacophylla Albizzia zygia Entada sudanica Dicrostachys glomerata Acacia macrostachya
	Annonacées	Annona senegalensis Hexalobus monopetalus
	Papilionacées	Pterocarpus erinacens lucens Erythrina senegalenses
	Combretacées	Combretum ghasalense Combretum glutinosum Combretum nigricans Combretum micranthum Combretum lamprocarpuns Terminalia avicennvides Terminalia laxiflora
	Rubiacées	Grossopterix febrifuga
	Verbenacées	Vitex madjensis Vitex spp.
	Olacacées	Ximenia americana
	Célastracées	Gynmosporia senegalensis
	Loganiacées	Strychmos spinosa Strychmos inocua
	Euphorbiacées	Phyllanthus discoideus Bridelia ferruginaea

	Myrtacées	Sizygium guinéense var macrocarpa
	Cesalpiniées	Pilios tigma reticulatum Pilios tigma thonningii
Lianes ligneuses	Apacynacées	Saba senegalensis Strophanthus sarmentosum
Herbacée	Graminées	Diheteropogon hagenrupii Elionurus elegans Sporobolus granularis Sporobolus festivus Sporobolus cormandelianus Digitaria gayana Loudetia togoensis Danthoniopsis tuberculata Andropogon pseudapricus Andropogon gayanus Cymbopogon giganteus Diectomus fastigiata Microchloa indica
	Amaranthacées	Pandiaka hendelotii
	Acanthacées	Dicliptera spp.
	Lythracées	Ammania auriculata Rotala welwitchii
	Convolvulacées	Ipomaea triloba Evolvulus alsinoides Ipomaea Kotschiana

8.5 Plaines alluviales à sols silico-argileux le plus souvent cultivés.

Tableau 11

Strate	Famille	Nom scientifique
Arborée et arbustive	Bombacacées	Bombax costatum
	Sapatacées	Vitellaria paradoscose
	Memosacées	Parkia biglobosa var africana Prosopis africana Albizzia spp. Entada sudunica Dicrostachys glomerata Acacia ataxacantha Acacia macrostachya

	Annonacées	Annona senegalensis
		Hexalobus monopetalus
	Ebenacées	Diospyrus mespiliformis
	Papilionacées	Pterocarpus erinceus
		Pterocarpus lucens
	Combretacées	Combretum ghasalense
		Combretum glutinosum
		Combretum spp.
		Terminalia avicennoides
		Terminalia macroptera
		Terminalia laxiflora
		Terminalia albida
	Rubiacées	Gardenia ternifolia
		Gardenia sokotensis
		Gardenia erubescens
		Gardenia triacantha
		Crossopterix febrifuga
	Hypericacées	Psorospermum glaberrimum
		Psorospermum senegalense
	Bignoniacées	Stereaspermum Kunthianum
	Polygalacées	Securidaca longipeduncilata
	Rhamuacées	Zizypthus mauritina
	Anarcardiacées	Lannaea acida
		Lannaea microcarpa
		Lannaea velutina
		Spendias mombin
		Heria insignis
	Moracées	Ficus gnaphalocarpa
		Ficus glumosa
		Ficus glumosa var glaberrima
		Ficus platyphylla
		Ficus capensis
		Ficus Kerstingü
Herbacée	Graminées	Pennisetum pedicellatum
		Digitaria debilis
		Digitaria velutina
		Digitaria chevalieri
		Eragrostis turgida
		Eragrostis pilosa
		Eragrostis tenella
		Eragrostis tremula

		Brachiaria ramosa
		Brachiaria deflexa
		Brachiaria lata
		Brachiaria hagerupii
		Brachiaria stigmatisata
		Acroceras zizanioides
		Sporobolus spp.
	Hipoxydacées	Curculigo plosce
	Asdépiadacées	Pachycarpus lineolatus
		Ectadiopsis oblongifolia
	Gingiberacées	Kaempferia aethiopica
	Oxalidacée	Biophytum Petersianum
	Capparidacées	Cleome viscosa
		Gynandropsis gynandra
		Cleome monophylla
	Polygalacées	Polygala arenaria
		Polygala multiflora

Dans les plains alluviales il faut distinguer aussi les adventices post-culturales et ruderales ; parmi elles on peut citer :

Tableau 12

Strate	Famille	Nom scientifique
Herbacées	Composées	Spheranthus senegalensis
	Acanthacées	Nelsonia canescens
		Monechma ciliatum
	Rubiacées	Oldenlandia herbacea
		Oldenlandia (Kohautia grandiflora)
		Kohautia confusa
		Borreria verticillata
		Mitracarpus scaber
	Barraginacées	Heliotropium indicum
		Coldenia procumbens
	Amaranthacées	Celosia trigyna
	Pedaliacées	Ceratotheca sesamoides
		Ceratotheca sesmoides var. grandiflor

8.6 Bas-fonds humides

Les bas-fonds humides représentent le (lit majeur) des cours d'eau et certaines dépressions qui recuillent les eaux pluviales. Les sols sont de nature argilo-sablonneuses ou limono-argileuse. Les eaux de pluie y sont retenues sur une période plus ou moins longue. Sur ces sols s'installe une savane à espéces pérennes. Le tableau 13 ci-dessous donne la liste des espèces :

Tableau 13

Strate	Famille	Nom scientifique
Arbustive	Rubiacées	Mitragyna inernis
	Rhamnacées	Zizyphus mucronata
	Combretacées	Terminalia macroptera
		Terminalia laxiflora
	Césalpiniées	Cynometra vogelii
		Daniellia oliveri
		Piliostigma reticulatum
		Piliostigma thonningü
	Mimosacées	Mimosapigra
Sous-ligneux	Papilionacées	Moghania faginea
	Graminées	Sorghastrum trichopus
		Hyparrhenia rufa
		Hyparrhenia dissoluta
		Brachiaria fulva
		Andropogon gayanus
		Andropogon pinguipes
		Themeda triandra
		Pobeguinia arrecta
		Schizachyrium brevifolium
		Schizachyrium platyphyllum
		Schizachyrium palustre
		Paratheria prostrate
		Echinochloa pyramidalis
		Echinochloa stagnina
		Echinochloa colona
		Setaria pallidefusca
		Setaria sphacaelata
		Oryza brachiantha
		Oryza barthii
		Oryza longistaminata
	Cyperacées	Scirpus praellongatus
		Cyperus schweinfurthianus
		Scleria tessellata

Les forêts-galéries de la savanne soudanienne constituent le prolongement de la formation climatique soudano-guinéene. On y rencontre les mêmes espèces végétales ou presque. Mais ces galeries-forêstières sont dans un état de dégradation très avancé. Quoiqu'il en soit, leur rôle comme refuges pour agents vecteurs de la maladie du someil de l'onchocercose est très important.

IX. AGRISTOLOGIE

Sur le plan agristologique les Terres-Nouvelles sont situées en zone soudanienne avec une pluviosité moyenne égale ou supérieure à 1.000 mm d'eau par an. Cette zone peut être subdivisée en deux secteurs qui sont le secteur nord soudanien situé entre les isohyètes de 800 et 1.100 mm ; le secteur sud soudanien situé entre 1.100 et 1.400 mm.

A. Secteur Nord-Soudanien

Ce secteur est caractérisé comme nous l'avons vu dans l'étude géobotanique, par la présence de Karité vitellaria et par le Andropogon ouagha. C'est un ensemble de formations végétales très claires, plus ou moins dégradées.

Les graminées qu'on y rencontre sont l'Andropogon gayanus, l'Andropogon pseudapricus, Diheteropogon hageruptü et le Pennisetum pedicellatum.

Le taux de recouvrement à la strate ligneuse est de 30 pourcent environ (IEMVT), celui de la strate herbacée de 45 à 50 pourcent environ.

B. Secteur Sud-soudanien

Il est caractérisé par la savane boisée à allure de forêt claire dans certains sites. Mais comme il a été indiqué plus haut, cette savane est en recul devant les feux et les défrichements de culture. Le secteur est le domaine de Isoberlinia doka et Uapaca samon. La strate herbacée est à prédominance d'Andropogon tectorum. La strate herbacée est à prédominance d'Andropogon tectorum. Le taux de recouvrement ligneux est de 60 pourcent environ (IEMVT).

A la strate herbacée on trouve les espèces suivantes :

Andropogon tectorum
Andropogon pseudapricus
Andropogon pinguipes
Diheteropogon amplecteus
Loudetia simplexe
Loudetia annua
Diectomis fustigiata

Dans les deux secteurs les zones d'inondation des cours d'eau portent une savane herbeuse avec les graminées vivaces suivantes :

Andropogon africanus
Hyparrhenia rufa
Sorghastrum trichopus
Setaria sphacaelata
Oryza brachyantha
Oryza barthii
Oryza longistaminata
Echinochloa stagnina
Echinochloa pyramidalis
Andropogon shirensis
Brachiaria fulva
Schizachyrium spp.
Scleria tessellata

9.1 Productivité des Pâturages naturels de la région

1. Secteur nord-soudanien

La production potentielle, compte tenu de la nature du substrat est estimée comme suit :

a. Pâturages à Andropogon pseudopiricus sur sols gravillonnaires : 800 kg/MS/ha.

b. Pâturages à Andropogon gayanus et Diheteropogon hageurupii sur terrasses colluviales : kg/MS/ha.

Methodologie de calcul de la capacité de charge (cette méthodologie est celle que la sous-section des pâturages naturels du CNRZ de SOTUBA propose).

c. Durée de pâture : elle est donnée par la relation suivante :

$$t = \frac{B}{2C}$$

dans laquelle t exprime le nombre de journées de pâture, B la biomasse ou productivité potentielle au niveau de l'écosystème prairial ; C la consommation journalière de l'UBT. Le coefficient 2 a été introduit pour indiquer que seuls les 50 pourcent des possibilités pastorales doivent être exploitées pour préserver le pâturage d'une dégradation possible.

Pour indiquer que seuls les 50 pourcent des possibilités pastorales doivent être exploitées pour préserver le pâturage.

d. Charge en UBT : elle est donnée par l'égalité suivante :

$$u = \frac{t}{365}$$

e. Capacité de charge en ha/UBT : elle est l'expression inverse de la charge en UBT soil.

$$ha = \frac{1}{u}$$

C'est le nombre d'hectares qu'il faut par an l'UBT. Ce facteur est très important à connaître en zones tropicales où l'animal est obligé de trouver la majeur partie de sa nourriture dans les pâturages naturels très éloignés les uns des autres.

f. Pâturages à Diheteropogon hageurupii et Pennisetum pedicellatums sur sol profond : 1.500kg/ha. La capacité de charge correspondant à chacun de ce types de pâturage est la suivante :

a. 64 journées de pâture/UBT/ha soit 0,17 BT/ha/an

b. 200 journées de pâture UBT/ha

0,54 UBT/ha/an
1,8 ha/UBT/an

c. 120 journées de pâture /UBT/ha

- 0,32 UBT/ha/an
- 3,1 ha/UBT/an

9.2 Secteur Sud-soudanien

Voici la production potentielle de quelques types de pâturages de ce secteur selon la nature du sol.

a. Pâturage à Andropogon tectorum et Diheteropogon amplecteurs sur sols squellettiques de plateaux. 3.000/ kg/MS/ha.

b. Pâturages à Loudetia simplex sur cuirasse (bouale) : 1.500/kg/MS/ha.

c. Pâturages à Andropogon gayanus et Hyparrhenia dissoluta 3.000/kg/MS/ha.

9.3 Savanes Herbeuses Des Deux Secteurs

8.000/kg/MS/ha. La capacité de charge dans chacun des pâturages est la suivante :

2a 240 journées de pâture

- 0,65 UBT/ha/an
- 1,5 ha/UBT/an

2b

- 160 journées de pâture
- 0,43 UBT/ha/an
- 2,3 ha/UBT/an

2c

- 120 journées de pâture
- 0,32 UBT/ha/an
- 3,1 ha/UBT/an

2d

- 240 journées de pâture
- 0,65 UBT/ha/an
- 1,5 ha/UBT/an

1.3

- 640 journées de pâture
- 1,7 UBT/ha/an
- 0,6 ha/UBT/an

APPENDIX B

AN OVERVIEW OF TRYPANO-TOLERANT CATTLE DEVELOPMENT POTENTIALITIES WITHIN THE MAIN TSE-TSE FLY BELT

An AID/AFR/CWR Technical Staff Paper
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December, 1974

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Most past cattle development programs have been directed toward improving the marketed output of Zebu cattle which inhabit the Northern Guinea and Sudan/Sahel Zones reflecting the greater numbers of cattle in these zones. The recent Sudano/Sahelian Zone drought brought to a focus the need to expand livestock development programs to the higher rainfall Guinea Zones if the rapidly expanding regional demand for meat is to be met.

Three approaches are feasible in developing tse-tse infested areas for livestock development:

1. fly control/eradication to eliminate the vector,

2. chemo-therapy as a disease control or prophylactic,

3. use of trypano-tolerant livestock

The choice in approach in any given area will depend upon the cost of control eradication methods, the type of vegetation and fly present, the availability of tolerant cattle and comparative profitability of tolerant versus non-tolerant cattle within the Guinea Zone.

INTRODUCTION:

The purpose of this paper is a preliminary overview of the potential for the expansion of meat production in West and Central Africa through the greater use of trypano-tolerant cattle.

Most of the major cattle surplus or exit zones in Africa are either free or substantially free of tse-tse fly species which are the vector of trypanosomiasis or African sleeping sickness. The fly-free zones of West Africa are for the most part in arid or semi-arid Sudanian or Sahelian ecological zones where the necessary habitat for tse-tse species of economic importance to livestock production are absent. Exceptions are limited areas at higher elevations where for various reasons, fly is either absent, producers can minimize contact with fly through seasonal migration or chemo-therapy is used as a control or prophylactic for the disease. With few exceptions, fly-free zones are seriously overgrazed and livestock numbers cannot be increased in these areas without the threat of further ecological damage.

TRYPANO-TOLERANT BREED TYPES: 1/

The present indigenous cattle of Africa can be conveniently divided into Bos Taurus (humpless) and Bos Indicus (humped) types, with numerous identifiable crosses between them (Map 1). Extant prototype trypano-tolerant cattle are traceable to either early humpless Longhorn stock introductions represented by the N'dama or later introduced humpless Shorthorn breed types which gave rise to the Muturu (West Africa Shorthorn). As a rule, the later introduced Zebu breeds are more susceptible to infection under similar degrees of tse-tse infestation and levels of management. Animals exhibiting lesser tolerance result from mixtures of Taurus and Zebu types.

1/ All domesticated cattle are descended from the wild urus which inhabited the west coast of the Pacific through Asia, Europe and Africa. Three distinct races were recognized: European or Bos Primigenius; Asiatic or Bos Nomadicus, and Northern Africa or Bos Opisthonomus.

The first domesticated cattle were of a Longhorn (Primigenius) type derived from Bos Nomadicus stock in Western Asia. They would have entered North Africa circa 5000 BC, where they were no doubt influenced by the local Bos Opisthonomus. This resulted in the humpless Longhorn Nilotic ox, often depicted in stone carvings of Pharonic times in Egypt.

In about 2500 BC a humpless Shorthorn (Brachyceros) ox that had also evolved in Western Asia, was introduced to Egypt. Over the past 3500 years, but especially in connection with the Arab expansion of the seventh century AD, numerous waves of humped or Zebu stock were introduced to north, and/or Nilotic Africa from Asia. The earliest of this type (circa 1580-1200 BC) would have been Cervico-Thoracic or neck-humped; whereas, those introduced by the Arabs (after 609 AD) were thoracic or chest humped. They have given rise to the modern type classifications of African cattle, Bos Taurus (humpless), Bos Indicus (humped or Zebu) and numerous crosses between them.

be effected by surface impoundment. Such ponds lend themselves to multi-purpose use, especially fish production. Day herding and night paddocking with limited stock handling facilities keep site costs low. Pasture improvement in the form of bush clearing, seeding with the better local grasses and legumes (Stylo and Centrocema), can be accomplished over time with hand methods, as herd numbers are built up. Production units can be groups of farmers, individual or government ranches and even private investors. With a medium of management, a 70% calf drop with 5 to 8% calf mortality can be realized. Grass fat steers weighing 500 pounds at 2 to 2-1/2 years are possible. With a herd extraction rate approaching 15%, such cattle are as productive as larger Zebus in the Sahelo-Sudan Zone.

There are both advantages and disadvantages in promoting trypano-tolerant cattle production as compared to improvement efforts with Zebu stock in the Sudan/Sahel Zone. The chief disadvantage or constraint relates to the limited number of improved trypano-tolerant cattle available in most countries, coupled with the need for demonstration centers to multiply and/or improve germplasm, demonstrate management practices and train would be producers in a complete package of production practices including mixed farming. Producers or production units would require credit or subsidy to establish stock water, livestock handling facilities and possibly for purchase of a nucleas herd or breeding bulls. It is to be noted that in many Francophone countries, trypano-tolerant cattle programs were earlier undertaken under a loan and repayment arrangement (Metayage) whereby farmers were provided with breeding units of one bull and five to fifteen cows, which were to be repaid in kind after some five years. In most cases, attention was also given to the use of animals for farm traction. In general, they are judged to have been quite successful projects although of a long-term nature, requiring 10-15 years to make an appreciable showing. This time frame is no longer, and perhaps less than that required to significantly change production practices among Sahelo/Sudan cattlemen.

The advantages of projects using trypano-tolerant cattle are varied. Generally, they are less handicapped by complex land tenure problems and a past history of taking milk as a major part of the daily diet. One starts with a clean slate and can introduce improved cattle production and marketing practices at the outset, under an integrated mixed farming program. Farm traction is a natural correlative, and herd surpluses would be expected to find a ready market as work oxen, breeding animals or for slaughter. Multipurpose dams lend themselves to the production of fish for local consumption, and limited irrigated vegetable production, in addition to providing dry season stock water. Moreover, there is less social disruption from displacing existing land users, overgrazing is not envisaged to be a problem and outside encroachment by nomadic producers on project sites is not a possibility.

In summary, it can be said that the recent drought accentuated the need to open up new grazing lands in the Northern Guinea Zone to relieve pressure on the Sahel/Sudan Zone. At the same time, it is axiomatic that there are limits beyond which Northern Zebu stock cannot be readily

Trypano-tolerant cattle either have or acquire a natural immunity to Trypanosomiasis, which is transmitted by the tse-tse fly. Different fly species transmit different trypanosome varieties which also differ as to their infectivity and pathology. Such immunity/tolerance is called premunition, whereby the tyrpanosomes occur in the blood in a state of balance with the host. This tolerance is believed to be specific to a given trypanosome and not in general. It can be broken down if an animal is under stress from malnutrition, lactation, overwork (animal traction) or disease. There is some indication that under prolonged absence of fly challenge, animals may lose a measure of earlier acquired tolerance. Certainly the phenomenon is little understood by scientists and only recently appreciated by animal resources development planners.

The chief domain of trypano-tolerant cattle lies within the main tse-tse belt of West and Central West Africa, normally receiving 1000 mm or more of annual rainfall (see Map 1). There is increasing interest in pushing the fly-free belt further south in order to permit the expansion of rangelands safe for Zebu cattle. However, in higher rainfall areas, control measures based upon insectival control or habitat modification become prohibitively expensive. Chemo-therapy as a long-term control method is believed to be infeasible because of the high probability of the development of drug resistant trypanosome varieties. Moreover, there are other constraints, apart from Trypanosomiasis that appear to or do detract from introducing Zebu stock into the Southern Guinea Zone. These include Streptothricosis, various tick borne diseases, flyworry caused by other biting flies (e.g., Tabnids and Stomoxys species) and soil mineral deficiency malnutrition.

There exists in almost every African country within the tse-tse belt, Derived or Guinea/Savanna Zones, belts that are vacant or only sparsely inhabitated and ill-suited to cropping, which could be developed for trypano-tolerant cattle production. In terms of assuring a meat supply over the long-term, such areas have enormous potentialities. At the same time, development is retarded by the limited number of trypano-tolerant cattle available and the need to evolve a generation of new cattle producers which do not have a past history of organized cattle production.

The carrying capacity of lands appropriate for trypano-tolerant cattle development is estimated to vary between 2 and 4 ha/AU, 2/ with only minimal site development. Dry season stock water would have to be provided for areas away from permanent streams, but this can usually

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2/ AU = animal unit, in range management a quantity in combination of number and mass having the feed intake requirement for optimum growth and reproduction equal to that of a mature cow, roughly, one bovine animal of any sex over one year, one ass, one horse, one camel, one Zebu, five goats or six sheep. As used here, the area of range required to carry one AU is one year. This compares to 6 ha/AU for the best Sudan range and 11 to 16 ha/AU for Sahel range.

pushed southward into the humid, high rainfall and main tse-tse belt of Africa. In particular, the southern- and derived Guinea Zones require a different ecological type of cattle as contrasted to the more northerly climates. The ever-increasing demand for beef and existence of trypano-tolerant cattle, now make it technically possible and economically feasible to introduce organized beef cattle production into vast, little-used areas of the main tse-tse fly belt.

Because USAID has national and regional offices in most West and Central African countries, the Agency could play an important coordinating role in reevaluating the place of trypano-tolerant cattle in the region. Because some of the countries lack the resources for a breeding and selection program, the Agency or supported organizations such as the ENTENTE Livestock Council could help in identifying superior animals and help make either breeding stock or semen available on a regional basis.

APPENDIX C

SELECTED LANDSAT IMAGE COVERAGE OF MALI

The following listing of LANDSAT images was compiled by Earth Satellite Corporation. It represents a selection of recent, excellent quality, low or no cloud cover scenes for the entire Republic of Mali. The list does not purport to be complete.

Selected images are identified by orbit and row numbers which correspond to the attached map. For example, Bamako is located in orbit 215/row 51. In many cases, more than one scene is listed, indicating excellent multi-date coverage, often over more than one season. Most of the images identified were acquired between November, 1975 and March, 1976. Only 0 and 10 percent cloud cover was allowed in this selected listing.

Reproductions of all images may be obtained either from Earth Satellite Corporation, Washington, D.C., U.S.A. or the EROS Data Center, Sioux Falls, South Dakota, U.S.A.

Orbite/Ligne nominale de l'image Orbit/Row	Numéro de l'image Image Number	mois/jour/an Mo/day/year	% d'Image couvert de nuages % cloud cover
206-47			
208-48	2429-09200	3/26/1976	0%
	2357-09215	1/14/1976	10%
	2339-09220	12/27/1975	0%
208-49	2429-09203	3/26/1976	0%
	2357-09221	1/14/1976	0%
207-46			
207-47	2430-09252	3/27/1976	0%
	2376-09265	2/2/1976	0%
	2322-09273	12/10/1976	0%
207-48	2430-09254	3/27/1976	0%
	2376-09272	2/2/1976	0%
	2322-09272	12/10/1976	0%
207-49	2403-09261	3/27/1976	0%
	2376-09274	2/2/1976	0%
207-50	2430-09263	3/27/1976	0%
	2376-09281	2/2/1976	10%
	2322-09284	12/10/1975	0%
208-46	2323-09325	12/11/1975	0%
208-47	2323-09331	12/11/1975	0%
	2287-09334	11/5/1975	0%
208-48	2323-09334	12/11/1975	0%
	2287-09340	11/5/1975	0%
208-49	2413-09323	3/10/1976	0%
	2323-09340	12/11/1975	0%
	2287-09340	11/5/1975	
208-50	2395-09332	2/21/1976	10%
	2377-09335	2/3/1976	0%
	2323-09343	12/11/1975	0%
209-45	2396-09370	2/22/1976	10%
209-46	2396-09372	2/22/1976	10%

Orbite/Ligne nominale de l'image Orbit/Row	Numéro de l'image Image Number	mois/jour/an Mo/day/year	% d'Image couvert de nuages % cloud cover
209-47	2396-09375	2/22/1976	10%
209-48	2396-09381	2/22/1976	10%
209-49	2432-09373	3/29/1976	0%
	2396-09384	2/22/1976	0%
	2378-09391	2/4/1976	0%
209-50	2432-09380	3/29/1976	0%
	2396-09390	2/22/1976	0%
	2378-09393	2/4/1976	0%
210-45	1509-09545	12/14/1973	0%
210-46	1509-09551	12/14/1973	0%
210-47			
210-48			
210-49			
210-50			
210-51			
211-44	1510-10001	12/15/1973	
211-45	2380-09485	2/6/1976	20%
211-46	2380-09492	2/6/1976	0%
211-47	2380-09494	2/6/1976	10%
211-48	2380-09501	2/6/1976	0%
211-49	2380-09503	2/6/1976	0%
211-50	2380-09510	2/6/1976	0%
211-51	2434-09495	3/31/1976	0%
	2398-09510	2/24/1976	10%
	2380-09512	2/6/1976	0%
211-52	2380-09515	2/6/1976	0%
212-44	1565-10041	2/8/1974	0%
212-45	1565-10044	2/8/1974	10%

Orbite/Ligne nominale de l'image Orbit/Row	Numéro de l'image Image Number	mois/jour/an Mo/day/year	% d'Image couvert de nuages % cloud cover
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212-47	2057-09582	3/20/1975	0%
212-48			
212-49			
212-50			
212-51	2399-09564	2/25/1976	
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212-53	2399-09573	2/25/1976	
213-43	2400-09590	2/26/1976	0%
213-44	2400-09593	2/26/1976	0%
213-45	2400-09595 1134-10151	2/26/1976 12/4/1972	
213-46			
213-47			
213-48			
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213-50	2400-10020	2/26/1976	0%
213-51	2400-10022	2/26/1976	0%
213-52	2400-10025 2040-10062	2/26/1976 3/3/1975	10%
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214-45	2401-10053	2/27/1976	10%
214-46			
214-49	2383-10074	2/9/1976	20%

Orbite/Ligne nominale de l'image Orbit/Row	Numéro de l'image Image Number	mois/jour/an Mo/day/year	% d'Image couvert de nuages % cloud cover
214-50	2383-10081 2365-10083	2/9/1976	10% 10%
214-51	2383-10083	2/9/1976	0%
214-52			
214-53	2023-10123	2/14/1975	
215-43			
215-44			
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215-50	2402-10132	2/28/1976	0%
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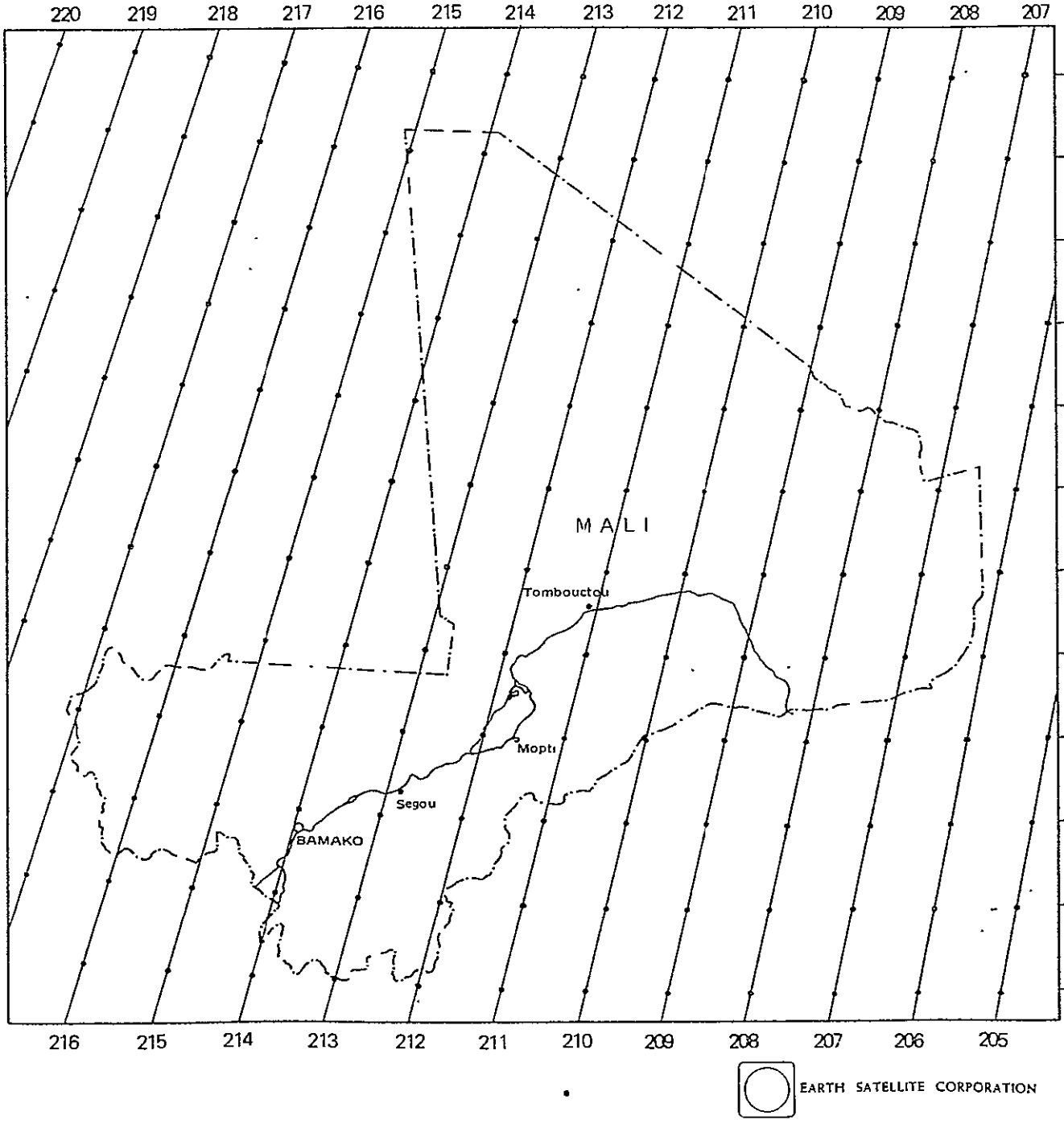
215-52	2402-10141	2/28/1976	0%
216-49			
216-50			
216-51			
216-52	2403-10195	2/29/1976	
217-49			
217-50			
217-51			

CARTE-INDEXE INDIQUANT LES ORBITES ET LES LIGNES NOMINALES
POUR LES REGIONS COUVERTES PAR SATELLITE LANDSAT

INDEX MAP FOR LANDSAT COVERAGE SHOWING ORBITS AND NOMINAL LINES.



APPENDIX D

DILLY MAPPING LEGEND: ECOLOGIC UNITS

Development and Importance

Resource surveys generate substantial amounts of diversified information that must be synthesized in order to be used effectively by scientists and resource planners. Much of this information is presented in map form on standard map bases or aerial photographs. The environmental or cultural information determined on the ground and from maps or aerial photographs and translated into selective meaningful classes or units is usually portrayed in the form of symbols and an accompanying descriptive legend. The creation of an effective legend is one of the most important steps in the application of resource information.

The ecological unit legend used in the Dilly Project was developed by resource ecologists and plant geographers involved in integrated natural resource surveys and has been modified over time in keeping with new developments in environmental classification and resource management operations (Poulton 1972). This land resource legend system allows characterization of land areas and water bodies into a hierarchical (graded or ranked) fashion capable of portraying varying levels of information at scales required for national, regional and district planning. The legend has been designed to be expandable to meet the needs of project planning and resource management at these various scales.

The legend design is based on the concept that vegetation reflects the unique environments occupied by each vegetational system. These unique environments are a product of the vegetation patterns and soils as they are affected by the physical surface of the landscape. Also incorporated into the legend are man-made and man-propagated entities existing within the natural environment, such as cities, villages, roads and agriculture. The legend system, as designed for the Dilly Project, reflects the kinds of vegetation classes traditionally mapped in West Africa on the basis of physiognomic and structural characteristics.

The Basic Ecological Unit (Land Resources) Legend.

The basic land resources legend consists of two parts: (1) A numeric (symbolic) legend which is computer compatible and appears within each unit delineated on the map, and (2) a descriptive legend which describes the numeric (symbolic) legend classes. The legend appears in fractional form reflecting the natural association of land cover and land use as it appears on the topography (Figure D-1).

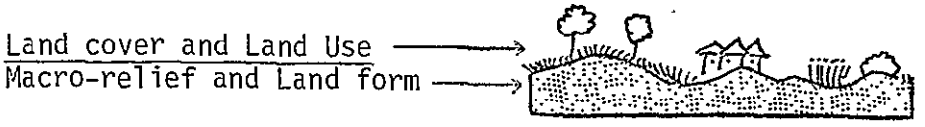


Figure D-1

The symbolic legend format is shown in Figure D-2, and in Figure D-3, as it would appear on one of the land unit delineations in the Dilly region.

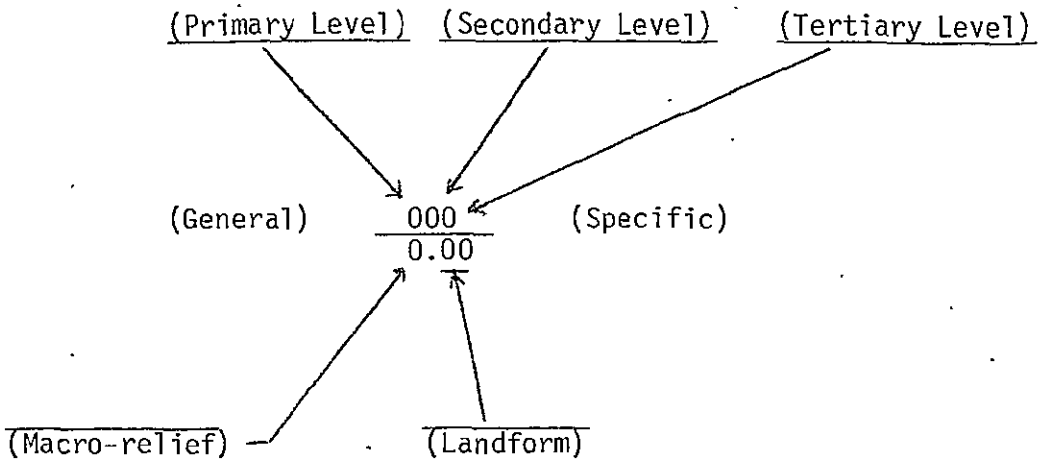


Figure D-2 Basic Ecological Unit Legend Format

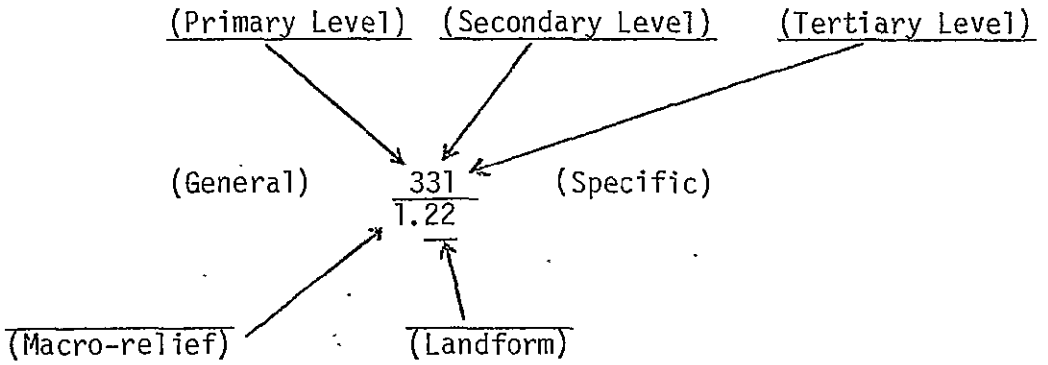


Figure D-3 Basic Ecological Unit Legend Format, Dilly Region, to Tertiary Level.

The numbers 100 through 900 in the numerator reflect the most general land cover classification, and 1 through 4 in the denominator, the most general topographic macro-relief classifications. In the Dilly area these primary level numbers for land cover are:

100 barren lands (other than fallow crops)
300 natural vegetation
500 agricultural crops and idle land
600 human settlements

The most general level of land form classification; macro-relief, is represented by two classes in the Dilly Region:

1. Flatlands
2. Undulating to rolling lands

There is a logical arrangement of environments from non-vegetated, to naturally vegetated, to man-modified landscapes. In more complex environments or larger area studies, the full range of classifications can include all numbers from 100 through 900. Similarly, land form classification reflects a logical progression moving from flatlands (1) to mountainous landforms (4). Hence, at the most general level, natural vegetation on a flat macro-relief will be written:

$$\frac{300}{1}$$

The secondary level of land cover/land use classification divides the vegetation into major sub-classes based on the physiognomic (appearance) or structural characteristics of the vegetation associations. The physiognomy (appearance) of these vegetation communities depends on their structure, and in turn, the structure includes the plant species and their horizontal and vertical distribution within the association. In the Dilly Region, the symbol 310 represents grasslands, 320 shrub/scrub vegetation, 330 savanna-like vegetation, and 340 woodlands.

The tertiary classification further subdivides the vegetation units into more refined physiognomic or structural levels. In the Dilly area, for example, 321 represents microphyllus (small-leaved) thorny shrubs such as Acacia seyal, and 326 indicates broad-leaved macrophyllous shrubs, such as Combretum spp.

Classification is carried to the tertiary level in the Dilly area, but it can be carried to the species level and further with the addition of decimal places in the designator. This would occur in very detailed site specific studies.

An example of a vegetation classification system proceeding from the primary to tertiary ecosystem level for Dilly is:

300 - natural vegetation (primary classification)
  330 - savanna-like vegetation (secondary classification)
    331 - tree savannas (tertiary classification)

The Relationship of the Land Cover/Land Use Ecological Unit Classification to Remote Sensing Techniques

The classification of vegetation communities depends on their structure. The structure includes the plant species types and their horizontal and vertical distribution within the association. Figure D-4 diagrammatically depicts three vegetation associations with differing physiognomic and structural characteristics.

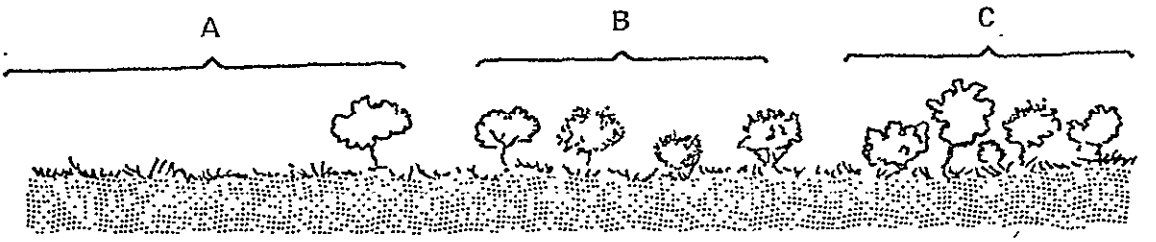


Figure D-4

All of the preceding associations would be classified together as 300, natural vegetation at the primary level, and are evident on LANDSAT satellite imagery at this general scale. At the secondary level, they would be called: A, grassland (310); B, savanna (330); C, woodland (340). The associations A and C would be discernible on LANDSAT, with a possibility of B also being described as a separate unit, depending upon the season. In most instances, the secondary level of classification is the limit obtainable from LANDSAT imagery without ground verification.

The three associations differing by this degree definitely could be defined at the secondary level using high altitude aerial photography (high flight) and more easily at intermediate scales of photography (1:50,000). At these scales, further refinement to the tertiary level classification, determining B as either tall tree savannah (331) or mixed tree/shrub savannah (333) is possible with ground verification. Grasslands (310) are classified as annual grasslands (311) and woodlands (340), are classified as dry season deciduous woodlands (342). It must be emphasized that the appearance of these environments in conjunction with ground verification lead to the tertiary level classification, as most trees, shrubs and grasses were unidentifiable as species at the scale of the available Dilly photography. In the Dilly region, the vegetation mapping units were carried to the tertiary level by interpreting color infrared and black-and-white aerial photographs and following up the interpretation by field work.

As the aerial photographic scale becomes larger (photography acquired at lower altitudes), legend classification becomes more detailed because vegetation species and associations are more easily recognized on the photography.

Development of the Physical Features (Landform) Ecological Unit Classification and its Relationship to Remote Sensing Techniques

The classification of the physical environment follows the same general to specific, hierarchical progression as does the land cover classification. In Dilly, there are two primary macro-relief classifications:

1. Flatlands
2. Undulating to Rolling Lands

Hilly (3), and mountainous (4), are major classifications not applicable to Dilly but possibly to other regions in Mali. Macro-relief features are the most obvious and reflect the highest level of generalization of the physical environment. They are most easily interpreted from space and high altitude imagery or photography.

Secondary physical features describe the landform classes that exist within each of the macro-relief classes. In the Dilly region secondary physical features are represented by:

.10 Depressional non-riparian landforms
.20 Bottomlands - riparian
.30 Planar surfaces
.40 Aeolian (wind laid surfaces)

Each of these, in turn, are subdivided into more refined forms within each of the secondary physical landform classes, for example, bottomland riparian is subdivided into:

.21 Narrow (stringer bottomlands)

.22 Wide river bottoms with flood plains and terraces (i.e., Valley of the Serpents)

A typical symbolic progression for the Dilly area from general to specific, macro-relief, to secondary landform is:

1. Flatland macro-relief

1.20 Riparian bottomland on flatland macro-relief

1.22 Wide river bottoms on flatland macro-relief

The physical features classification can be carried beyond the secondary landform level of detail, eventually describing soils and surficial geology. As in the land cover/land use classification, mapping capability and classification detail depends upon the scale of imagery used and intensity of field operations.

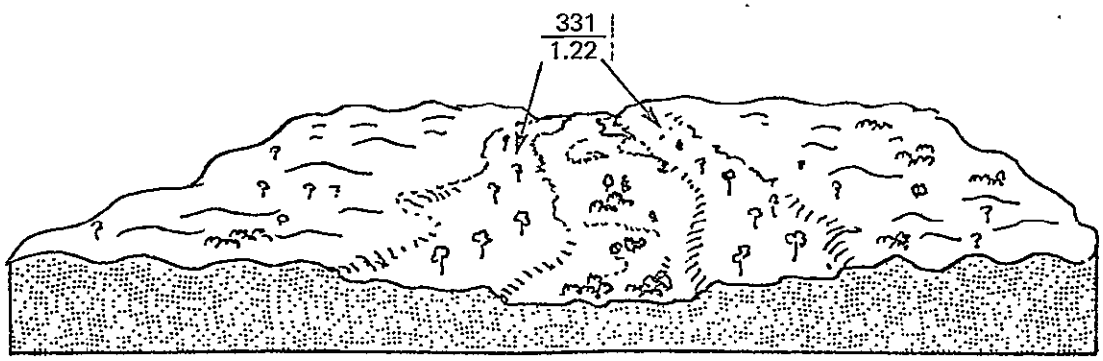


Figure D-5

Figure D-5 is an example of an ecological unit combining a tree savanna growing on a wide river bottom with Flood Plains and Terraces, symbolically noted as $\frac{331}{1.22}$

Ecological Unit Complexes

More than one land cover/landform classification can be assigned to an ecological mapping unit. This is called a complexed mapping unit, as opposed to the "pure" mapping unit represented in Figure D-5. Complexed units are recorded in decreasing order of component area or importance. For example:

$$\frac{311/500}{1.31/1.12}$$

Indicated above is a complex of annual grassland and field crops on plains and small depressional landforms. The field crops and the land cover designator and the small depressions in the landform designator occupy the smaller areas or are less significant in the complex. Not more than three components should be mapped either in the land cover or landform categories. If a vegetation association is determined to occupy less than 20 percent of the area symbolized, it is called an inclusion, and is not written in the legend symbol.

Letter values are assigned to complexes when an estimation of the areas occupied by each component of a complex are made. The symbol below depicts an ecological unit complex:

$$\frac{A311/510}{1.31}$$

This describes an environment with 80 percent annual grassland and 20 percent field crops on a plains environment. The code for proportional areas within the delineations is as follows:

No letter symbol = Pure Type

A = .8/.2
B = .7/.3
C = .6/.4 and .5/.5
D = .6/.2/.2 (1 is slightly more than 1/2 of the unit, the two others are approximately equal)
E = .5/.3/.2 (1 is approximately 1/2 of the area of the unit, others are not equal)
F = .3/.3/.3 (all are about equal)

Range Production Descriptors

Range production is determined by the air-dried weight of the grass species sampled within a specific environment in kilograms per hectare (Kg/ha). Production is symbolized as follows:

H = high production, 2500 Kg/ha or over
M = medium production, 1500-2500 Kg/ha
F = low production, 1500 Kg/ha or less

Where vegetation is complex, the production is proportioned by percent of specific complex and pro-rated. For example, A331/311 would mean that the total production for that ecological unit is 80 percent of the 331 classification plus 20 percent of the 311.

For example, production of the tree savanna (331) association in wide river bottom terraces is 2,300 Kg/ha, and 2,000 Kg/ha for annual grasslands (311) in the same environment. Since 80 percent of the ecological unit component is tree savanna (331), the pro-rated production is 1,840 Kg/ha and 400 Kg/ha for the 20 percent of the area that is in annual grasslands. 1,840 Kg/ha plus 400 Kg/ha is 2,240 Kg/ha, or within the medium (M) production range.

Area Measurement Component of the Ecological Unit Descriptors

The area of each ecological unit is determined in square kilometers and included in the descriptor. An example of a complete ecological unit descriptor combining all the possible symbolic elements appears below in Figure D-6.

$$\frac{\text{A } 331/311}{1.22} \cdot \frac{\text{M}}{15}$$

Figure D-6

The descriptor above describes an ecological unit of 15 square kilometers, consisting of 80 percent tree savanna, 20 percent grasslands located on a wide riparian bottomland. The production of the two components of the complex is determined to be medium. Figures D-7 and D-8 summarize in hierarchical fashion the descriptors comprising the ecological unit classification system.

LAND COVER AND LAND USE FEATURES LEGEND

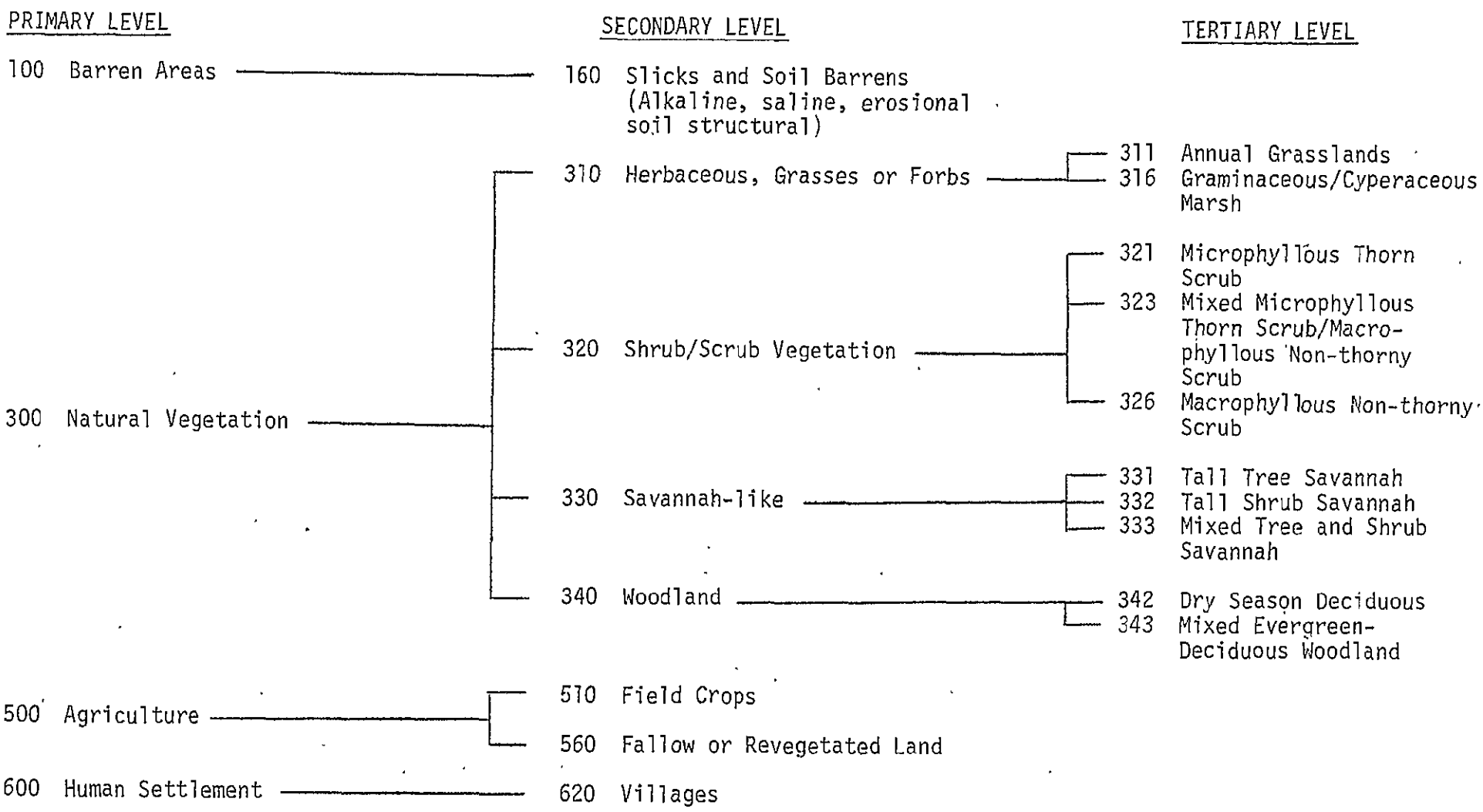


Figure D-7

PHYSICAL ENVIRONMENT LEGEND

MACRO-RELIEF	PRIMARY LANDFORM	SECONDARY LANDFORM
1. Flatlands	.10 Depressional, non-riparian	.11 Basins, Interior Drainage usually with Playas or Lakes
		.12 Small Depressional Areas
	.20 Bottomland, riparian	.21 Stringer or Narrow Bottomland
		.22 Wide River Bottoms with Floodplains and Terraces
2. Undulating to Rolling Lands	.30 Planar Surfaces	.31 Plains
		.32 Plateaus and Benches
		.33 Pediments (With inclusions of Inselbergs)
	.40 Aeolian Land Form Systems	.41 Sand Sheets and Plains
		.42 Sand Complex (Knob-like hills of white dunes with associated depressions)
		.43 Ergs with Associated Depressions

Descriptors for Proportional Area Components Within Land Cover Complexes

No letter symbol = Pure Type
A = .8/.2
B = .7/.3
C = .6/.4 and .5/.5
D = .6/.2/.2 (1 is slightly more than 1/2 of the unit, others are approximately equal)
E = .5/.3/.2 (1 is approximately 1/2 of the unit, others are not equal)

Range Production Descriptors

H = high production, 2,500 Kg/ha or over
M = medium production, 1,500-2,500 Kg/ha
F = low production, 1,500 Kg/ha or less

Ecological Unit Area Measurement

Appears in square kilometers under Range Production descriptor in the legend

Figure D-8

DESCRIPTIVE MAPPING LEGEND, DILLY REGION

Land Cover and Land Use Features

This section defines the environmental and cultural entities included in the land cover/land use features portion of the ecological unit legend.

Primary Class

100 - BARREN LAND; Barren land is somewhat relative but it is intended to cover all situations where the earth's surface is essentially barren rock, stones and gravel, or mineral soil. It is impossible to specify a vegetational cover percentage or threshold for barren land. For example, a talus slope with a few shrubs around the periphery or rarely within the talus would still be mapped in a barren land class. Desert or sparse steppe vegetation causes the greatest problem. If the natural ecosystem in a desert climate is sparsely vegetated, it would fall into one of the vegetated desert classes, usually symbol 320, even though total percentage ground cover may be well under 10 percent. Experience has shown that barren land subclasses should never go beyond tertiary level and frequently it is unnecessary to go beyond secondary. To do so makes the barren land class redundant with geological information where the latter is assessed as a component of the physical environment or land surface.

Secondary Classes

160 - SLICKS AND SOIL BARRENS (ALKALINE, SALINE, EROSIONAL, SOIL STRUCTURE): Bare areas with 10 percent less vegetation cover. These can be areas with high salt, silt or clay contents, or alluvium in low or bottomland areas, and wind-swept or bare areas in the sand sheets and plains or plateaus and benches.

Primary Class

300 - NATURAL VEGETATION: This class includes natural or native vegetation consisting of indigenous species or introduced species that have become naturalized to the region and that have found an ecological niche as though they were a part of the original vegetation. This class includes all successional stages in the natural vegetation. In mapping and identification, one should avoid trying to map the presumed "climax" or eventual equilibrium vegetation, but rather should map and identify vegetation as it exists at the time imagery was obtained. The postulation of climax areas comes later as an interpretation of the basic inventory.

Secondary Class

310 - HERBACEOUS TYPES: That vegetation (annual, biennial, or perennial) which in aspect is dominantly herbaceous - including any or all grasses, grass-like plants and forbs. By definition, herbaceous vegetation includes small, tender plants lacking woody stems. Broad-leaved herbs are forbs, as distinguished from the narrow-leaved grasses (Dansereau, 1957).

Tertiary Class

311 - ANNUAL GRASSLANDS: Land area dominated by annual grass vegetation. Tree or shrub cover is generally estimated to be 5 percent or less. Only a few perennial grasses were found in the Dilly area (landforms 1.22, 1.31 and 2.43) and were not mapped or included in the legend.

316 - GRAMINACEOUS/CYPERACEOUS MARSHES: Hygric (very wet) vegetation dominated by mixtures or dense stands of individual grasses, rushes and sedges, found in depressional areas, adjacent to or in ponds near villages and in some of the riparian areas.

Secondary Class

320 - SHRUB/SCRUB VEGETATION: Shrubs are small, woody plants having several stems branching near the ground. Shrubs are generally smaller than trees (Dansereau, 1957). In some cases there is difficulty in establishing a difference between trees and shrubs both in growth habit and size. Often a plant species may grow in both forms in different locations. Mature, woody plants growing from approximately 5 to 6 meters were classified as shrubs in the Dilly Region.

Shrubs are the prominent vegetation and these may or may not form a closed layer; however, in this classification, the herbaceous layer is subordinate. The herbaceous ground layer of this vegetation is highly variable and can be important. The aspect is one of a relatively low woody vegetation.

Tertiary Class

321 - MICROPHYLLOUS THORN SHRUB: Small, leaved, armed (thorny) shrubs generally dominant in dryer areas, for example, Acacia seyal spp.

323 - MIXED MICROPHYLLOUS THORN SCRUB/MACROPHYLLUS NON-THORNY SHRUB: Mixed community of small-leaved, thorny and broad-leaved, non-thorny shrubs.

326 - MACROPHYLLOUS NON-THORNY SCRUB: Broad-leaved, unarmed shrubs, typified by, for example, Combretum ghasalense spp.

Secondary Class

330 - SAVANNA-LIKE TYPES: The world literature in no way agrees on the definition of a savanna. We have therefore been specific in applying the following descriptive definition that fits most temperate and many tropical situations where the expression savanna has been used to describe a unique community of plants. For the purposes of this survey, savanna vegetation consists of sparse, taller, woody plants interspersed somewhat regularly throughout by a more dense low shrub or herbaceous layer to give a distinct two-storied community, with the lower layer the more prominent. Tree and shrub covers of approximately 5 to 15 percent can be used to add a quantitative dimension to the definition.

Tertiary Classes

331 - TREE SAVANNA: The woody plant community consist of tree forms such as Sterculia setigera and Bombax costatum. This association is the most distinct two-layered community in appearance. Sometimes termed arborescent savanna.

332 - TALL SHRUB SAVANNA: Similar in many respects to the arborescent savanna-like type except for the dominance of a shrub-like woody plant overstory in place of the tree-like forms of the arborescent savanna. Taller forms of Commiphora, Combretum and Sclerocarya species are logical woody plant forms in this association, not to be confused with types where shrub or tree cover are dense enough to be classified as woodlands.

333 - MIXED TREE AND SHRUB SAVANNA: Contains both tree and shrub forms in a savanna-like association. Does not appear as distinct a two-layered community as in the arborescent savanna.

Secondary Class

340 - WOODLANDS: The tree layer forms the dominant vegetational feature. This layer often forms a closed canopy over a variety of subordinate vegetation layers.

Tertiary Class

342 - DRY SEASON DECIDUOUS WOODLANDS: Deciduous or semi-deciduous woodlands found mostly on the plains, pediment, and dune areas.

343 - MIXED EVERGREEN DECIDUOUS WOODLANDS: Woodlands found in the depressional or riparian areas and in the swales of dunes, but sometimes found in upland landforms.

Primary Class

500 - AGRICULTURAL PRODUCTION: These are land areas cleared of the natural vegetation and managed by agronomic principles for production of food, fiber or fodder crops. The class includes land areas or structures, facilities and agricultural practices directly related to subsistence farming. These agricultural lands are characterized by the relatively constant effect of man through manipulation of the vegetation and micro-environment (fertilization, mulching, irrigation, etc.).

The class also includes permanent pasture managed for maximum yield by fertilization, irrigation and periodic renovation. These are pastures generally included within or in juxtaposition with the crop field boundary.

Secondary Classes

510 - CROPLANDS, COVER CROPS: Field fiber and seed crops. Millet and sorghum are the principal crops grown in the Dilly area.

560 - NON-PRODUCING AND TRANSITIONAL CROPLAND: Fallow; plowed, hoed (or variously worked), and leached cropland including harvested fields. Included here are abandoned or idle croplands, fields, and pastures as well as entrapped lands that are isolated from effective agricultural production by being surrounded or blocked from access by class 600 lands (villages).

Primary Class

600 - URBAN INDUSTRIAL AND TRANSPORTATION (HUMAN SETTLEMENT): Includes all urban, industrial and transportation centers and arteries. Most of this classification does not apply to the Dilly area because of its rural and isolated location.

Secondary Class

620 - VILLAGES: Largest centers of habitation in Dilly area. Generally subsistence agriculture oriented, but may serve as collection centers through which the raw products may be transported to the cities. Can eventually be subdivided into tertiary classes of 621 and 622, large and small villages, respectively when appropriate criteria are selected.

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